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FINAL REPORT ON FIELD DEMONSTRATION OF AVIATION TURBINE FUEL MIL-T-83133C, GRADE JP-8 (NATO CODE F-34) AT FORT BLISS, TX

INTERIM REPORT
BFLRF No. 278

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A field demonstration was conducted at Ft. Bliss, TX, to determine the feasibility of using JP-8 fuel (MIL-T-83133C, NATO Code F-34) in U.S. Army ground combat/tactical vehicles and equipment (V/E) in lieu of DF-2 diesel fuel. The demonstration was conducted during the period 1 February 1989 through 30 September 1991. The results of the demonstration for the period 1 February 1989 through 31 July 1990 were reported in Interim Report BFLRF No. 264, entitled "Field Demonstration of Aviation Turbine Fuel, MIL-T-83133C, Grade JP-8 (NATO Code F-34) at Ft. Bliss, TX." After 31 July 1990, Operation Desert Shield/Storm resulted in the deployment to the Middle East of over 2,000 of the initial 2,800 plus V/E participating in the demonstration at Ft. Bliss, leaving approximately 750 V/E for the remaining demonstration interval through 30 September 1991. There was no significant return of V/E to Ft. Bliss by the end of the program. However, by that time, it was apparent that initial results reported in Interim Report BFLRF No. 264 were verified during the remainder of the demonstration.

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These results were: (1) there were no statistically significant differences observed in average fuel consumption rates for combat/tactical V/E when using JP-8 fuel; (2) where power loss was apparent in only a few power-limited engine systems, generally it was commensurate with the difference in heating values between JP-8 and DF-2; (3) no catastrophic failures due to the use of JP-8; (4) all fuel-related problems surfaced by user personnel were resolved by technical consultation or direct comparison tests with DF-2; (5) JP-8 fuel is acceptable for use in military diesel-powered ground equipment systems, and (6) the lack of a capability to produce a persistent smoke screen still prohibited its use in some combat vehicle engine exhaust smoke systems (VEESS).

EXECUTIVE SUMMARY

Problems and Objectives: Although Operations Desert Shield/Storm (ODS) occurred at a most inopportune time, it emphasized the need to continue the JP-8 fuel demonstration program at Ft. Bliss, TX. Over 2,000 diesel fuel-consuming vehicles and items of support equipment (V/E) were deployed from Ft. Bliss to Saudi Arabia, leaving about 750 V/E at the base. It was essential that the demonstration program be continued to verify earlier findings.

Importance of Project: With the advent of ODS and the concerns expressed by combat commanders about using Jet A-1 fuel with which they were not familiar, the concept of "One Fuel on the Battlefield" could survive only if forthright and timely answers were provided. Information and data derived from the continued JP-8 fuel demonstration program at Ft. Bliss helped provide valuable reassurance that the concept was valid and continued to permit the acquisition of data about the long-term effects of using JP-8 in military diesel-burning ground assets. The existence of the JP-8 fuel demonstration program at Ft. Bliss, even with fewer combat/tactical vehicles and support equipment, facilitated the continued use of Jet A-1 during ODS as the experience being generated was continually being transitioned into the various Emergency Operation Centers (EOCs) at AMC, TACOM, TROSCOM, and QM School to support those units operating on Jet A-1.

Technical Approach: Operational and maintenance data continued to be acquired by program field monitors. Engine oil degradation and oil change interval data were provided by the U.S. Army Materiel Readiness and Support Activity (MRSA), and mileage data were provided by The Army Maintenance Management System (TAMMS). Most data were loaded into respective data bases, and statistical analyses were performed to produce comparisons between V/E response to JP-8 usage versus DF-2 usage.

Accomplishments: The JP-8 fuel demonstration was successfully concluded on 30 September 1991. The program demonstrated that JP-8 fuel can be used as a primary fuel in military aviation and diesel-burning ground vehicles and equipment in lieu of DF-2. It also demonstrated that no modifications to V/E or handling and storage equipment are required. The program resulted in JP-8 becoming the primary fuel of choice for Ft. Bliss, TX, and Ft. Hood, TX, to be utilized in aviation and diesel-burning ground assets.

Military Impact: The program demonstrated the potential for significant reductions in operational costs due to reduced maintenance of fuel systems and fewer replacement of fuel system components. Further, the reduction in logistics, both in substance and costs, by using a single fuel for aviation and military ground assets is expected to be substantial. Because JP-8 is a more stable fuel and is cleaner burning than DF-2, a substantial increase is expected in wartime preparedness and combat readiness.

FOREWORD/ACKNOWLEDGMENTS

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Acknowledgment is given Messrs. LePera and Bowen, SATBE-FL, Ft. Belvoir, VA, for their participation, encouragement, and support. Also acknowledged are the Materiel Readiness and Support Activity (MRSA) for providing selected operational and oil degradation data that were absolutely essential in establishing a data base against which later data, also supplied by them, could be compared, the Army Maintenance Management System (TAMMS) for providing mileage data, and the General Materiel and Petroleum Activity (GMPA) that rendered valuable assistance in obtaining certification for above-ground bulk fuel storage at Ft. Bliss, TX, and helping in achieving aviation quality fuel deliveries to Ft. Bliss.

The authors would like to acknowledge Mr. Steven L. Willhoite, analyst, SwRI, for his support in the computer data base formulations and summaries and to all the Ft. Bliss personnel who participated in the demonstration program for their willing support and timely data. Special mention is given to Mr. William Condes, chief, Tasking Branch, Directorate for Plans Training and Mobilizations; Mr. P.L. King, chief, Component Repair Facility, Directorate for Industrial Support (DIS); Mr. Robert E. Galindo, chief, Transport Branch, Transportation Division, Ft. Bliss, TX; and Ms. Mary Cintron, JP-8 POC, Plans and Operations Division DIS, for their enthusiastic support and guidance throughout the program. Special mention is also given to LTC Noel R. McLaughlin, chief, Ft. Bliss USA Logistics Assistance Officer (LAO); and Mr. James W. Rose, Jr., senior logistics management specialist, Logistics Assistance Representative (LAR); and the other LAR specialists making up the LAO team for the timely and effective assistance and coordination rendered the BFLRF monitor team, BFLRF, and Belvoir RDE Center.

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I. BACKGROUND

The U.S. Department of Defense (DOD) has historically purchased a wide range of fuels for its compression ignition (CI) engines. These fuels include diesel grades DF-A, DF-1 and DF-2, NDF, and aviation jet kerosene grades JP-5 and JP-8. (1-5)* The choice of which fuel to use depends to a large extent upon the type of service, ambient conditions, availability of the fuel in the locale, and cost. Different engines have different fuel requirements, and different missions may well demand different fuels for the same engine. Because of the diversity of fuels and requirements, a substantial fuel logistics burden exists in the DOD. Sudden changes in ambient conditions or mission requirements may necessitate a change in fuel that may not be quickly supportable by the supply system. This difficulty was demonstrated in the winter of 1981-82 when diesel-fueled ground equipment in Europe had severe startability problems caused by fuel wax plugging the engine fuel filters as well as nozzle plugging problems. (6) These problems were the result of the cloud point of the standard NATO diesel fuel (Code F-54) in combination with a sudden (lower than expected) cold front to which the fuel supply system could not react.

For many years, the U.S. Navy has been using JP-5 to fuel planes and helicopters in shipboard and land-based service. JP-5 was used rather than JP-4 because the higher flash point requirement of JP-5 makes shipboard handling of the fuel safer in the event of a spill or crash. Since the JP-5 was already stored aboard ships and at Navy bases, it was very efficient to run diesel engines on it rather than provide separate tankage for DF-2. A series of tests were performed at Port Hueneme, CA, in the mid-1960s to determine the impact of using JP-5 in diesel engines. The results of the study indicated that JP-5 was an acceptable alternate to DF-2 for the diesel engines then assigned to the Naval Construction Forces. (7-9) Use of JP-5 in lieu of DF-2 resulted in a reduced logistics burden in shipboard and remote locations.

During the early 1970s, Army agencies were requested to consider the use of JP-5 as an alternate fuel for all equipment powered by CI engines. Based on the Navy's work at Port Hueneme, surveys of engine and component manufacturers, short-term testing conducted by the Army, and a comprehensive knowledge of miliary engine fuel requirements, the Army subsequently approved JP-5 as an alternate to VV-F-800 fuels in September 1978. (10) The impetus for using JP-5 was primarily focused on equipment operating OCONUS where the predominant fuel requirements were in support of the U.S. Navy.

In subsequent years, substantial interest in the DOD has existed in the use of JP-5 and JP-8 as CI fuels. This interest was based on the good low-temperature properties of the fuels (low cloud point) as well as the logistics benefits of using the same fuel for aircraft and ground equipment. Because of this interest, the Army conducted numerous investigations on the use of JP-5 and JP-8 in compression-ignition engines. (11-15)

*Underscored numbers in parentheses designate references at the end of this report.

Recently the **Single Fuel On The Battlefield Concept** has captured the attention of fuels logisticians in the DOD. Essentially this concept would move the tactical fleet toward the use of one fuel in a given theater of operation. The potential for logistics benefits is large considering the amount of fuel used in both aviation and ground equipment. Indeed, use of the same fuel for aviation and ground equipment would serve as a combat-force multiplier since all equipment could be refueled in forward areas, eliminating movement to rear areas to obtain special/variety fuels.

Army Regulation (AR) 703-1 published on 5 January 1987 (10) upgraded JP-8 from an emergency fuel to an alternate fuel for diesel-fueled vehicles and equipment (V/E). DOD Directive 4140.43 was issued on 11 March 1988, specifying primary fuel support for overseas land-based air and ground forces be accomplished using JP-8, or JP-5 if more appropriate. DOD Directive 4140.43 is paralleled by a draft North Atlantic Treaty Organization Standardization Agreement (i.e., NATO STANAG 4362) entitled "Fuel Requirements in Future Ground Equipment," which was developed in October 1987 and is now in final coordination. Availability of JP-8 within NATO for ground equipment applications is not an issue since NATO ministers already agreed to convert from the highly volatile Aviation Turbine Fuel, Grade JP-4 (NATO Code F-40) (3) for military aircraft to the much safer JP-8/F-34 fuel in September 1986, with the agreement ratified in January 1987.

II. INTRODUCTION

In April 1987, the NATO Pipeline Committee agreed to conversion from NATO Code Nos. F-40 to F-34 aviation fuel for all military aircraft being operated by NATO Forces. This action gave impetus to the concept of a single fuel on the battlefield. However, some initial concerns were raised relative to using NATO Code F-34/F-35 as a diesel fuel. U.S. Army Tank-Automotive Command (TACOM) and U.S. Army Training and Doctrine Command (TRADOC) representatives believed there may be some credence to such concerns as potentially unsatisfactory service (e.g., lower power, increased fuel consumption, etc.) perceived safety problems due to JP-8's lower flash point, vehicle warranty/engine warranty questions, and the nonsmoking properties of NATO Code No. F34/35 fuels. TACOM and TRADOC were also concerned that user confidence with the JP-8 fuel needed to be established.

During the fall 1987 to spring 1988 time period, the Army Materiel Command (AMC) and its appropriate major subordinate commands conducted the planning required to formally verify acceptance of JP-8 in all diesel fuel consuming ground equipment. After a coordination meeting in June 1988 at the Army Tank-Automotive Command, representatives from the Troop Support Command's (TROSCOM) Belvoir Research Development and Engineering Center and TACOM concurred and proposed a technology demonstration program be conducted at Ft. Bliss, Texas. The Army's Training and Doctrine Command and Forces Command (FORSCOM) concurred with the AMC proposal, and Ft. Bliss accepted the invitation to provide cooperation

and support the program. It was agreed that all work at Ft. Bliss connected with the JP-8 Fuel Demonstration Program was to be conducted on a noninterference basis having no impact on mission/training schedules.

A two-phased plan of action was adopted. Phase I was a limited short-term series of vehicle evaluations that measured the differences in fuel consumption and vehicle performance between DF-2 and JP-8. The results of Phase I are contained in References 16 and 17. Phase II was to be a broad-scale user demonstration/fleet evaluation of JP-8 as an acceptable alternate fuel in diesel-fuel consuming ground equipment. Ft. Bliss was chosen as the demonstration site because it (1) had a proper mix of combat, combat support, and tactical vehicles and equipment most of which had V/E groups, i.e., battle tanks, armored personnel carriers, and trucks, that were in sufficient numbers to represent a statistically significant sample size for each V/E group in the program; (2) has consistently high ambient temperatures during the summer months to provide needed severity and maximize the effects of using the lower viscosity JP-8 fuel; and (3) had previously participated in cooperative-type programs and exhibited outstanding cooperation and willingness to participate.

Liaison/coordination meetings with designated Ft. Bliss personnel were conducted by Belvoir Fuels and Lubricants Research Facility (BFLRF) personnel to ensure the preparation, adoption, and smooth implementation of a demonstration program plan. A program design plan (18) and a standing operating procedure (SOP) (19) were prepared by BFLRF that resulted in a Letter of Instructions (LOI) (20) being issued by the Ft. Bliss Director of Logistics (DOL), now known as the Director of Installation Support (DIS). The LOI formally ratified the design plan and SOP and tasked the appropriate organizations, agencies, and activities at Ft. Bliss for cooperation and support of the overall program.

III. DEMONSTRATION PROGRAM OBJECTIVES

The objectives of the JP-8 Demonstration at Ft. Bliss were to:

1. Demonstrate acceptability in using JP-in all vehicles and equipment designed to consume diesel fuel.
2. Identify whether use of JP-8 will create user problems in either combat/tactical or combat support vehicles and equipment.
3. Within the scope of the demonstration program:
   a. Define changes in average fuel consumption.
   b. Define cost benefits/cost avoidance projections in using JP-8 for diesel-powered ground vehicles and equipment.
4. Determine the need for development of a user/operator manual of changeover from diesel to JP-8.

IV. FUEL PROPERTIES AND COMPARISONS

TABLE 1 lists military/civilian diesel and turbine (i.e., middle distillate) fuels referred to in this report. Also shown in TABLE 1 are the appropriate NATO code designations, military or civilian specifications, and the fuel's common name. Listing of the special "M1 Fuel" in TABLE 1 requires further explanation. Low-temperature operability problems were never major issues in Europe until the introduction of the M1 Main Battle Tank and the Patriot systems in 1981. The agreed upon cloud and pour point limits for F-54 that had been established in 1975-76 were reasonably satisfactory for all NATO countries except Norway. The U.S. Army in Germany adopted the policy of blending equal quantities of DF-2 (F-54) and JP-8 to relieve most of the low-temperature problems. This mixture, which was subsequently used by all diesel-fueled V/E in forward areas during November through April, is now interchanged under NATO Code F-65, or referred to simply as the "M1 Fuel." (6)

TABLE 1. Fuel Designations, Code, Specifications

Common Name	NATO Designation	NATO Title	U.S. Military/Federal Specification	U.S. Civilian Standard
JP-4	F-40	Turbine Fuel, Aviation, Widecut Type + FSII (S-748)	MIL-T-5624 Turbine Fuel, Aviation, Grade JP-4	ASTM D 1655 Turbine Fuel, Jet B
JP-8	F-34	Turbine Fuel, Aviation, Kerosene Type + FSII (S-748)	MIL-T-83133 Turbine Fuel, Aviation, Kerosene, Grade JP-8	NE*
Jet A-1	F-35	Turbine Fuel, Aviation, Kerosene Type	MIL-T-83133 Turbine Fuel, Aviation Kerosene, Grade JP-8 Plus Grade F-35	ASTM D 1655 Turbine Fuel, Jet A-1
JP-5	F-44	Turbine Fuel, Aviation, High-Flash Type + FSII (S-1745)	MIL-T-5624 Turbine Fuel, Aviation, Grade JP-5	NE
Kerosene	F-58	Kerosene	NE	ASTM D 3699 Kerosene
DF-2, DF-1, DF-A	NE	NE	VV-F-800 Fuel Oil Diesel, Grade DF-2, DF-1, DF-A, "CONUS" only	ASTM D 975, Diesel 2-D, 1-D
DF-2	F-54	Diesel Fuel, Military	VV-F-800 Fuel Oil Diesel, Grade DF-2 (OCONUS)	NE
"M1 Fuel"	F-65	"Winter Fuel Blend,," 1 Part F-54 with 1 Part Either F-34 or F-44	NE	NE
2-D	NE	NE	VV-F-800 Fuel Oil, Diesel, Grades DF-1 & DF-2 (CONUS)	ASTM D 975, Diesel 1-D & 2-D
NDF	F-76	Fuel, Naval Distillate	MIL-F-16884 Fuel, Naval Distillate	NE
*NE = No Equivalent				

TABLE 2 contains comparative properties associated with DF-2, JP-8, Jet A-1 (21), JP-5, DF-1, and DF-A. Note that JP-8 (NATO Code F-34) is identical to ASTM D 1655 Jet A-1, which is interchanged by NATO countries under NATO Code F-35, except JP-8 contains mandatory fuel system icing inhibitor, corrosion inhibitor, and static dissipator additive. The numbers shown in parentheses with "footnote B" in TABLE 2 are average values from an earlier survey (14) that are provided for comparison purposes.

TABLE 2. Comparison of Selected Fuel Specification Requirements Related to Diesel and Turbine Engine Performance

Properties	VV-F-800D				MIL-T-5624N JP-5/NATO Code F-44	MIL-T-83133C JP-8/NATO Code F-34	ASTM D 1655 Jet A-1/ NATO Code F-35
	DF-A	DF-1	DF-2	DF-2 (OCONUS)*			
Flash Point, °C, min	38	38	52	56	60	38	38
Cloud Point, °C, max	-51	**	**	13	NR†	NR	NR
Pour Point, °C	Rpt	Rpt	Rpt	18	NR	NR	NR
Freezing Point, °C, max	NR	NR	NR	NR	-46	-47	-47
Kinematic Viscosity at 40°C, cSt	1.1 to 2.4	1.3 to 2.9	1.9 to 4.1	1.3 to 5.0(A)	NR(1.50)(B)	NR(1.25)(B)	NR(1.25)(B)
Kinematic Viscosity at -20°C, cSt, max	NR	NR	NR	NR	8.5	8.0	8.0
Distillation, °C							
10% recovered, max	NR	NR	NR	NR	205	205	205
20% recovered, max	NR	NR	NR	NR	Rpt	Rpt	Rpt
50% recovered, max	Rpt	Rpt	Rpt	NR	Rpt	Rpt	Rpt
90% recovered, max	288	288	338	357	Rpt	Rpt	Rpt
End Point, max	300	330	370	370	290	300	300
Residue, vol%, max	3		3	3	3	1.5	1.5
Carbon Residue on 10% Bottoms, wt%, max	0.10	0.15	0.35	0.2	NR	NR	NR
Sulfur, mass%, max	0.25	0.50	0.50	0.30	0.40	0.30	0.30
Cu Corrosivity							
3 hr at 50°C, max	3		3	3	1	NR	NR
2 hr at 100°C, max	NR	NR	NR	NR	1		1
Ash, wt%, max	0.01	0.01	0.01	0.02	NR	NR	NR
Accelerated Stability, mg/100 mL, max	1.5	1.5	1.5	1.5	NR	NR	NR
Neutralization Number, mg KOH/g, max	0.05	NR	NR	0.1	0.015	0.015	0.015
Particulate Contamination, mg/L, max	10		10	10	10	1.0	1.0
Cetane Number, min	40	40	40	45	NR(42.3)(B)	NR(44.9)(B)	NR(44.9)(B)
Net Heat of Combustion							
MJ/kg, min	NR	NR	NR	NR	42.6	42.8	42.8
Btu/gal.	NR	NR	NR(130,575)(B)	NR(127,776)(B)	NR(125,965)(B)	NR(123,138)(B)	NR(123,138)(B)
Corrosion Inhibitor, mg/L	NR	NR	NR	NR	QPL-25017	QPL-25017	NR
Antiicing Additive, vol%	NR	NR	NR	NR	0.15 to 0.20	0.10 to 0.15	NR
Electrical Conductivity, pS/m	NR	NR	NR	NR	NR	150-600	NR/50-450

*Meets all requirements of NATO Code F-54 Guide Specifications; OCONUS refers to Outside Continental United States.
**Specified according to anticipated low ambient temperature at use location.
† NR = No Requirement.
(A) Kinematic Viscosity values given are equivalent to NATO requirement of 1.8 to 9.5 cSt at 20°C.
(B) Average value from Reference No. 14 shown for comparison purposes.

Fig. 1 shows a graphical representation of the boiling range of the middle distillate fuels referred to within this report.

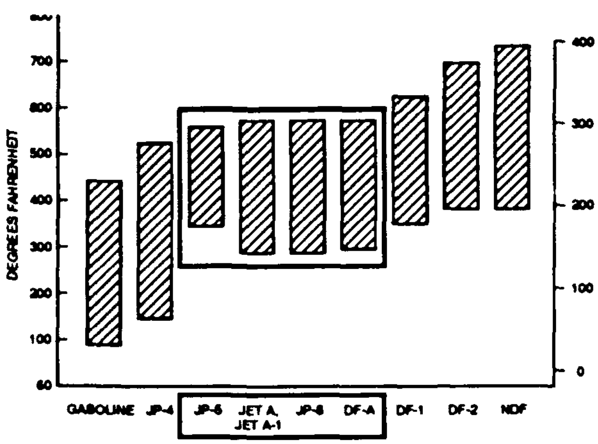


Fig. 1 - Boiling ranges of diesel/turbine fuels

V. METHODOLOGY

A. Participating Organizations

The following Ft. Bliss organizations participated in the JP-8 demonstration program:

- • • 3rd Armored Cavalry Regiment (3rd ACR)
- • • 11th Air Defense Artillery Brigade (11th ADA Bde)
- • • 6th Air Defense Artillery Brigade (6th ADA Bde)
- • • 70th Ordnance Battalion (70th Ord Bn)
- • • Range Command
- • • Ft. Bliss Transportation Motor Pool (TMP)

B. Vehicles and Equipment

Initially over 2800 vehicles and ground support equipment were included in the JP-8 demonstration program. Some vehicles were removed from the program during the report period due to normal attrition, programmed changes in types of vehicles (i.e., replacement of M113 Armored Personnel Carriers (APC) by Bradley M3 fighting vehicles) and deployment to Saudi Arabia for Operation Desert Shield/Storm. Reference 22 provides a complete density listing of V/E participating in the program at Ft. Bliss. It should be noted that while essentially all equipment was switched to JP-8 fuel, only those diesel consuming V/E enrolled in the Army Oil Analysis Program (AOAP) could be included in the actual data base. Unfortunately this eliminated the Commercial Utility Cargo Vehicle (CUCV) and High Mobility Multipurpose Wheeled Vehicle (HMMWV) since these are not enrolled in the AOAP. Table 3 summarizes the major types of the diesel fuel-consuming V/E mix at Ft. Bliss for the period 1 February 1989 through approximately 29 September 1990 (prior to Operation De-

TABLE 3. Population of Major Fleet Equipment in Ft. Bliss Demonstration

Type	1 Feb 89 through 29 Sept 90	30 Sept 90 through 30 Sept 91
Combat Tracked Vehicles	584	40
Tactical Wheeled Vehicles	1823	490
Generator Sets	306	117
Material-Handling Equipment	72	50
Construction Equipment	21	35
TMP Administration Vehicles	39	37
Total	2845	769

sert Storm (Column 2) and the period approximately 30 September 1990 through 30 September 1991 (Column 3).

A breakdown of the V/E composite mix showing high-density items and the applicable fuel injection system is included in TABLE 4.

TABLE 4. Summary Breakout of Ft. Bliss Fleet (Approximately 30 Sept 90 through 30 Sept 91)

Type	Number	Fuel Injection System
Tracked Carriers	36	Unit Injector
M48A1 (Chaparral)	4	Rotary-Bosch
Gun Air Defense	19	Unit Injector
Trucks, 2-1/2 Ton, 5 Ton	148	Rotary-Bosch; PT System
Trucks, 3/4 Ton, 1-1/4 Ton	185	Rotary-Stanadyne
Trucks, 10 Ton, HEMTT	98	Unit Injector
Generators, 5 kW	11	Rotary-Bendix
Generators, 10 kW	2	Rotary-Bendix
Generators, 15 kW	53	Rotary-Stanadyne
Generators, 30 kW	17	Rotary-Stanadyne
Generators, 60 kW	18	Rotary/PT System
Generators, 150 kW	16	Turbine System

C. Data Acquisition Procedures

It must be reemphasized that all data acquisition for the JP-8 demonstration was to be conducted on a noninterference basis at Ft. Bliss having no impact on routine mission/training schedules. To accomplish the required coordination to achieve the program objectives, it was necessary to place near full-time BFLRF technical monitors on-site at Ft. Bliss in nearby El Paso, TX. Close proximity enabled the BFLRF monitors to keep abreast of all matters pertaining to the JP-8 program and to provide prompt professional assistance or advice as required. The on-site Logistics Assistance Representatives (LAR) within the U.S. Army Materiel Command Logistics Assistance Office (AMC-LAO) reported all problems, perceived or substantive, to the BFLRF monitor team. Problems were resolved through technical consultations, or comparative tests in which the same or like V/E were operated back-to-back with DF-2 and JP-8. The data base content for this demonstration included those sources of information shown in TABLE 5.

TABLE 5. Data Sources for JP-8 Demonstration at Ft. Bliss

Item No.	Information Collected	Data Source
1	Ambient Temperature History	National Climatic Data Center
2	Bulk Fuel Dispensings	Directorate of Installation Support (DIS)
3	Fuel Samples; Analyses	On-site Monitors; BFLRF, USA GMPA
4	Fuel Transition Periods	DIS; Sample Analysis
5	Fuel Wetted Components Usage	Army Maintenance Form 2407
6	Mileage (km)/Hours of Operation	The Army Maintenance Management System (TAMMS)
7	Fuel Consumption Data	Merger of Vehicle Fuel Dispensing from Army Form 3643 with AOAP mileage (km) data
8	Other mileage (km); Fuel Consumption	Selected Units: 6th Air Defense Artillery Brigade; Transportation Motor Pool Administrative Vehicles
9	Engine Oil Degradation	AOAP: Oil change interval, wear metal levels
10	Resolution of User/ Maintenance Concerns	On-site monitors investigation; back-to-back fuel-related comparisons
11	Major Field Exercises	Unit Command Personnel

D. JP-8 Bulk Fuel Logistics

Belvoir RDE Center provided funding assistance to Ft. Bliss to permit Ft. Bliss engineers, plumbing, and grounds personnel to accomplish several small projects that were essential to the timely initiation of the JP-8 Demonstration Program. These projects included repair or replacement of components for a railway spur into the BAAF bulk storage area for increased safety; upgrading an electrical terminal at BAAF to meet safety standards; installing two 500-gal./min fuel transfer pumps, allowing a separate fuel outlet pipe line to be installed from the main fuel storage tank to the fuel delivery station; and installing an operations and administration building for Ft. Bliss POL personnel. To ensure that the JP-8 Demonstration Program would not interfere with normal operations at Ft. Bliss, Belvoir RDE Center also provided funds for two additional salaried fuel handlers at BAAF for the first year of operations and one fuel handler for the remainder of the program. Funds were also provided for a contract between Ft. Bliss and a local fuel company to provide JP-8 fuel to the Ft. Bliss Range Command at McGregor Firing Range and the 2/7th Air Defense Artillery Battalion (2/7th ADA Bn) located at McGregor Firing Range.

JP-8 fuel was delivered to the Biggs Army Air Field (BAAF) fuel storage area from which using organizations, agencies, and activities drew fuel. The JP-8 fuel was added to existing DF-2 diesel fuel in bulk fuel storage tanks and individual V/E fuel cells. All participating organizations, agencies, and activities continued normal missions/training activities. Provisions were made to have JP-8 fuel available to the 3rd ACR during its training exercises at the National Training Center, Ft. Irwin, CA. Appendix A provides more detail on Bulk Fuel Logistics for the demonstration.

E. Fuel Sampling and Analysis

Fuel samples were taken on a selective basis from commercial fuel delivery transports, bulk fuel storage tanks, fuel handling/dispensing equipment and individual V/E fuel cells. Fuel samples were shipped to BFLRF for laboratory analyses. In addition to results from these samples, results of analyses of fuel samples routinely taken by Ft. Bliss personnel and shipped to the General Materiel Petroleum Activity (GMPA) Lab West were provided to BFLRF. Further explanation of fuel sampling/analysis is provided in Appendix A.

F. Operation and Maintenance Data Collection

Items numbers 6 through 9 in TABLE 5 were derived by statistical treatment of raw data obtained from (1) individual Vehicle Fuel Dispensing data on Army Form 3643, and (2) individual vehicle mileage (km) data from the Army Maintenance Management System (TAMMS), which is compiled through Army Oil Analysis Program (AOAP) samples. Individual vehicle fuel consumption was computed by merger of these two data bases. These raw data were collected for the DF-2 baseline and JP-8 use periods from nine units assigned to two Air Defense Artillery (ADA) Brigades (6th and 11th) and one Armored Cavalry Regiment (3rd ACR) at

Ft. Bliss, TX. These nine units are 11th ADA (2/1st, 5/62nd, and 3/43rd Battalions); 6th ADA (1/43rd and 2/6th Battalions); and 3rd ACR (1/3rd, 2/3rd, 3/3rd, and Support Squadrons).

The individual vehicle fuel dispensing and mileage (km) data collected were examined with the purpose of eliminating obvious erroneous raw data points that may lead to inaccurate average vehicle miles or miles-per-gallon (mpg, km/L) estimates. After merger of the data bases and subsequent individual vehicle miles-per-gallon (km/L) computation, validity of the data were assessed by statistical outlier checks. (22-23) A total of 46 mpg (km/L) data values were eliminated from the entire data collection of computed values. Also, sample size tables (24) were consulted to establish minimum sample observations required for comparing appropriate vehicle group average fuel consumptions for differing fuel use periods. The minimum sample size determined was 17 observations for each group being required in order to detect a difference with probability equal to 0.90. Although average values were computed for all groups that contained at least 2 observations, only those with size greater than or equal to 17 were compared statistically. To determine if the average mpg (km/L) values were different between the DF-2 and JP-8 fuel periods, a classical statistical method of comparing averages by using the t-test statistic was initially employed. (25) However, in the analysis of the oil degradation data, assumption violations related to the t-test statistic forced the use of a nonparametric statistical test (Wilcoxon Rank Sum Test) when comparing the wear metal readings and oil change data across the two fuel periods. Additional explanation of data collection methodology is provided in Reference 22 with regard to: (1) Fuel consumption (dispensings) data; (2) Mileage (km) of operation data; (3) Autonomous operational data base for 6th ADA Brigade; (4) Autonomous operational data base for Ft. Bliss Transportation Motor Pool (TMP); and (5) Oil Degradation Data.

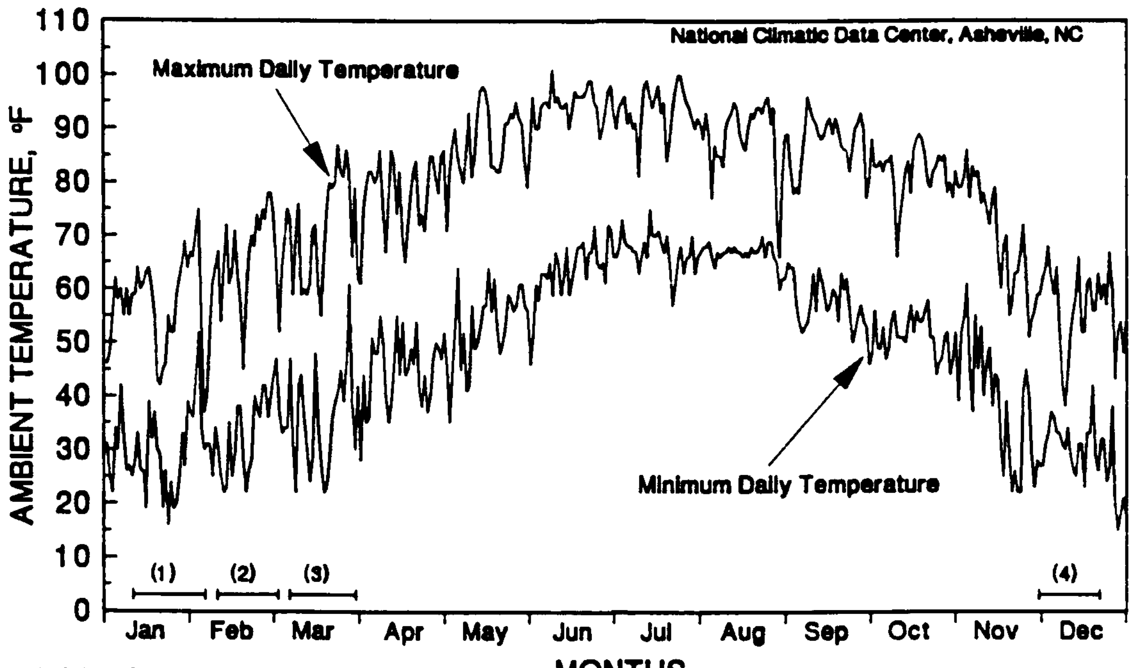
VI. JP-8 DEMONSTRATION RESULTS

A. Ambient Temperature History

Ambient temperature history was received from the National Climatic Data Center, Asheville, NC for El Paso, TX (Ft. Bliss) and Barstow, CA (Ft. Irwin). The National Training Center, Ft. Irwin, CA, is located about 30 miles east and north of Barstow, CA. The ambient temperature histories and training exercises for Ft. Bliss are shown in Figs. 2 through 5. Data provided for 1988 are for diesel fuel baseline purposes. It is noted that the Ft. Irwin temperature history shown in TABLE 6 includes only those months during which the 3rd ACR was training at the NTC. Review of these data confirms that the JP-8 fuel was exposed to the high ambient temperatures desired for this demonstration.

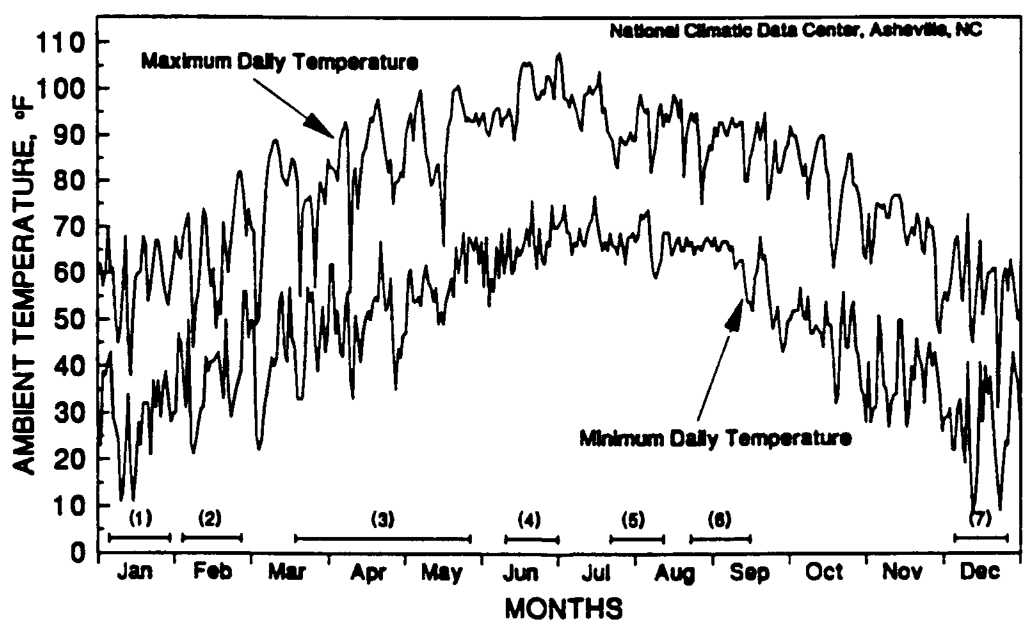
B. Baseline Diesel Fuel Samples

BFLRF monitor personnel took 11 middle samples and 18 bottom samples of DF-2 from underground storage tanks of participating organizations and activities motor pools and forwarded



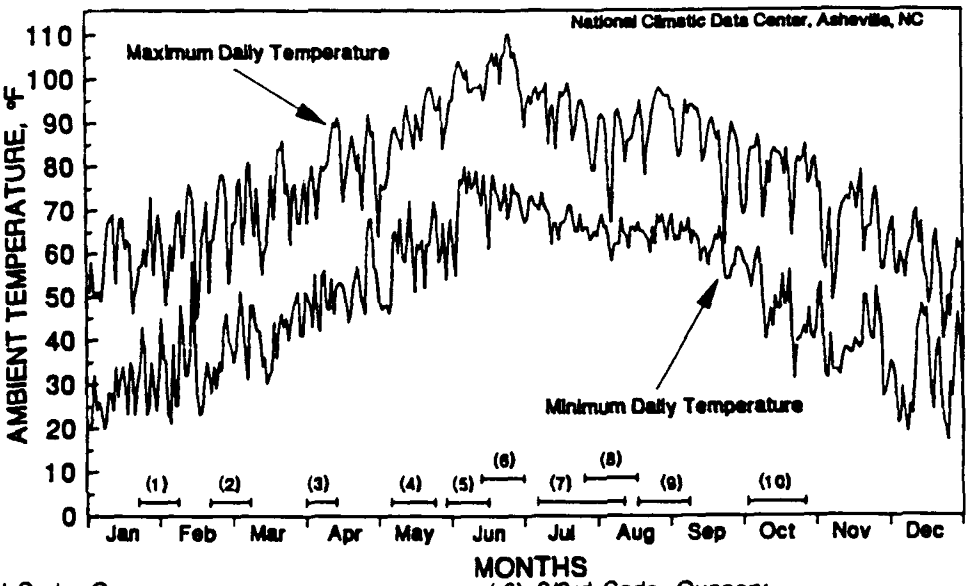
(1) 3/3rd Sqdn, Gunnery
(2) 2/3rd Sqdn, Gunnery; 194th Armored Brigade (Ft. Knox, KY training visit)
(3) 1/3rd Sqdn, Gunnery; 3rd ACR Caisson Challenge (M109 Hows)
(4) 2/3rd Sqdn, Gunnery

Fig. 2 - Temperature variations and training exercises at Ft. Bliss, TX (Calendar Year 1988)



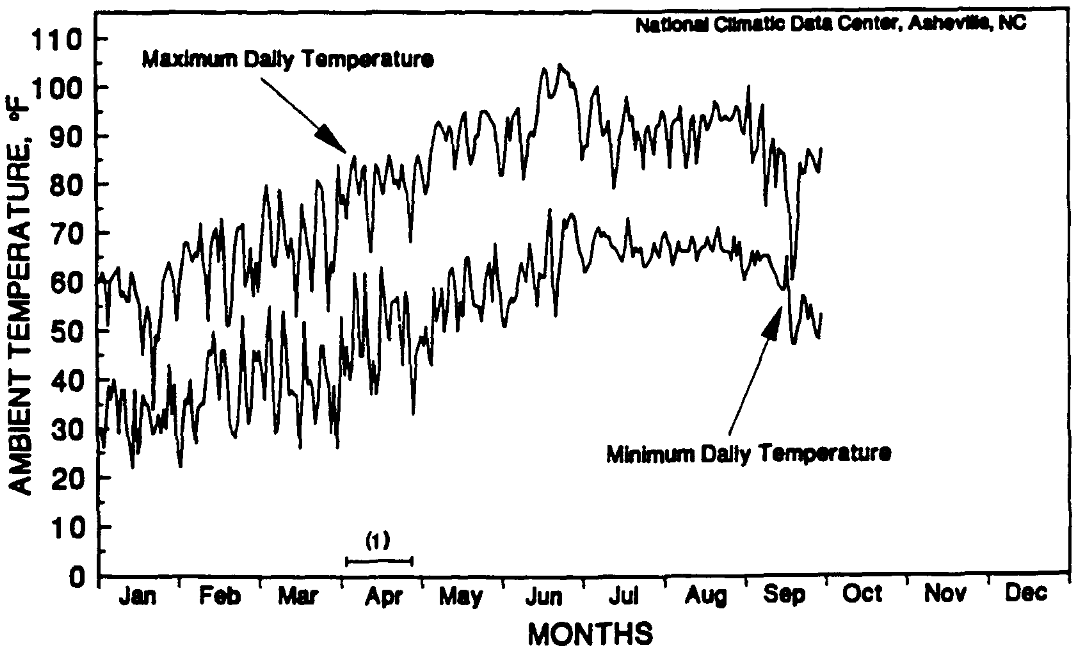
(1) 1/3rd Sqdn, Gunnery
(2) 3/3rd Sqrd, Gunnery
(3) 3rd ACR Regimental, FTX
(4) 2/3rd ACR, Bradley M3 Exercise
(5) 2/3rd Sqdn, Gunnery
(6) 3rd ACR Howitzers Live Fire; 1/3 Sqdn, Gunnery; 11th ADA Bde, "Roving Sands-89"
(7) Caisson Challenge (M109 Hows)

Fig. 3 - Temperature variations and training exercises at Ft. Bliss, TX (Calendar Year 1989)



(1) 3/3rd Sqdn, Gunnery
(2) 2/3rd Sqdn, Gunnery
(3) 3rd ACR Regimental, FTX
(4) 11th ADA Bde, "Roving Sands-90"
(5) 1/3rd Sqdn, Gunnery
(6) 3/3rd Sqdn, Gunnery
(7) 2/3rd Sqdn, Gunnery
(8) USAR 85th Div (TNG), Field Exercises (M60 Tank)
(9) 3rd ACR Regimental, FTX
(10) 6th ADA Bde, ARTEP

Fig. 4 - Temperature variations and training exercises at Ft. Bliss, TX (Calendar Year 1990)



(1) 1/43rd ADA Bn, 6th ADA Bde, Field Exercises

Fig. 5 - Temperature variations and training exercises at Ft. Bliss, TX (1 January-30 September 1991)

TABLE 6. Ambient Temperature, °F (°C) at Ft. Irwin, CA*

Month	Year/Fuel	Avg. Maximum	Avg. Minimum	Highest	Lowest
October	1987/DF-2	90 (32)	56 (13)	105 (41)	49 (9)
May	1989/JP-8	98 (37)	60 (16)	112 (44)	42 (6)
October	1989/JP-8	87 (30)	50 (10)	101 (38)	32 (0)

*Temperatures for Ft. Irwin were provided by the Barstow Fire Station Weather Observing Site, Barstow, CA, through the National Climatic Data Center, Asheville, NC.

TABLE 7. Average Results of Analyses of DF-2 Middle Samples (Baseline for JP-8 Comparison)

Property	ASTM Method	Average Results (11 Samples)
TAN, mg KOH/g	D 3242	0.015
Aromatics, vol%	D 1319	34.2
Olefins, vol%	D 1319	2.1
Sulfur, mass%	D 4294	0.36
Hydrogen, mass%	D 3178	12.6
Distillation, °C, % Recovery	D 86	
Initial Boiling Point		196
10%		227
20%		238
50%		265
90%		314
End Point		342
Residue, vol%		1.0
Gravity, °API	D 1298	33.4
Density, kg/L	D 1298	0.8577
Cloud Point, °C	D 2500	-17
K. Vis, cSt,		
at 40°C	D 445	2.57
at 70°C	D 445	1.57
Net Heat of Combustion, MJ\kg	D 240	42.305
Btu/lb (Btu/gal.)		18,188(129,959)
Cetane Number	D 613	44
Cetane Index	D 976	44
Existent Gum, mg/100 mL	D 381	6.2
Particulate Contamination, mg/L	D 2276	4.8
Accelerated Stability, mg/100 mL	D 2274	1.9
Visual	D 4176	Cl/Br to Sed/Br*

the samples to BFLRF for laboratory tests and analyses. The average results of middle sample analyses are presented in TABLE 7. Three of the middle samples exceeded the VV-F-800D specification limit of 1.5 mg/100 mL for the accelerated stability test, ASTM D 2274 resulting in the high average. These three samples also had higher existent gum values (3.5 to 21.4 mg/100 mL) than the other samples. One sample also exceeded the specification limit of 10 mg/L for particulate contamination. The results for the bottom samples varied; however, several of the samples had visible water or sediment and dark color.

C. JP-8 Routine Samples

Routine samples were taken on a regular basis to confirm the quality of the JP-8 fuel being dispensed at Ft. Bliss, as well as the grade and quality of the fuel in the underground storage tanks. Together with the bulk fuel dispensing data, the results of the sample analyses served to confirm when the post was fully converted to JP-8 fuel. TABLE 8 is a summary, by quarter, of typi-

TABLE 8. Properties for JP-8 Fuel in the Ft. Bliss Biggs Army Air Field (BAAF) Main Tank (By Quarter)

Property	ASTM Method	MIL-T-83133C JP-8 Requirements	1st Quarter	2nd Quarter	4th Quarter	5th Quarter	6th Quarter	7th Quarter	Averages
TAN, mg KOH/g	D 3242	0.015, max	ND (1)	0.003	0.003	0.006	0.006	0.004	0.004
Aromatics, vol%	D 1319	25.0, max	ND	17.8	14.6	16.9	17.1	17.0	16.7
Olefins, vol%	D 1319	5.0, max	ND	2.5	1.2	1.6	1.3	1.4	1.6
Sulfur, mass%	D 4294	0.30, max	0.03	0.03	0.01	0.04		0.04	0.03
Hydrogen, mass%	D 3178	13.4, min	13.67	13.69	13.9	13.54	14.09	14.02	13.82
Distillation, °C	D 86								
Initial Boiling Point		Report	181	182	176	174	175	178	178
10% Evaporated		205, max	199	202	191	194	191	190	195
20% Evaporated		Report	ND	207	195	198	194	194	198
50% Evaporated		Report	219	219	206	208	204	207	211
90% Evaporated		Report	245	242	230	233	228	232	235
End Point		300, max	266	266	269	263	265	253	264
Residue, vol%		1.5, max	1.0	1.0	1.0	1.0	0.5	0.5	0.8
Gravity, °API	D 1298	37 to 51	41.9	42	46.6	44.6	46.4	44.2	44.3
Density, kg/L	D 1298	0.840 to 0.775	0.8147	0.8152	0.7941	0.8032	0.7950	0.8050	0.8045
Cloud Point, °C	D 2500	NR (2)	ND	-60	-50	-53	-53	-54	-54
Flash Point, °C	D 93	38, min	ND	ND	53	60	56	60	57.3
K. Vis, cSt, at									
40°C	D 445	NR	ND	1.55	1.30	1.37	1.30	1.36	1.38
70°C	D 445	NR	ND	1.05	0.90	0.94	0.91	0.95	0.95
Net Heat of Combustion	D 240								
MJ/kg		42.8, min	43.026	43.015	43.294	43.259	43.236	43.0	43.138
Btu/lb		18,400, min	18,498	18,493	18,613	18,598	18,588	18,504	18,549
Btu/gal.		NR	125,791	125,685	123,233	124,532	123,206	124,185	124,438
Cetane Number	D 613	NR	ND	42.8	47.0	46.5	47.6	46.6	46.1
Cetane Index	D 976	Report	45.5	45.9	49.4	46.5	48.5	45.1	46.8
Existent Gum, mg/100 mL	D 381	7.0, max	ND	0.4	0.8	1.5	1.3	1.8	1.2
Particulate Contamination, mg/L	D 2276	1.0, max	ND	0.6	0.6	7.1	0.8	1.0	2.0
Accelerated Stability, mg/100 mL	D 2274	NR	ND	0.2	0.1	0.2	0.1	0.1	0.1
FSII, vol%		0.10 to 0.15	0.07	0.09	0.13	0.09	0.10	0.05	0.09
Fuel Conductivity, pS/m		150 to 600	170	75	120	100	70	90	104
Corrosion Inhibitor, mg/L†		QPL-25017	Trace	19.2	8	ND	9	16.4	13.2
Visual	D 4176	Clean/Bright	ND	Clean/Bright	Clean/Bright	Sed/Hazy	Clean/Bright	Clean/Bright	Clean/Bright
Colonial Pipeline Co. Haze Rating	Proposed	NR	ND	ND	1	2	1	1	1
Color	D 156	Report	+30	ND	+24	+20	+30	ND	+26

*1st QTR = 1 February - 30 April 1989; No 3rd Quarter Data Available.
(1) ND = Not Determined
(2) NR = No Requirement.
† Based on HITEC E580.

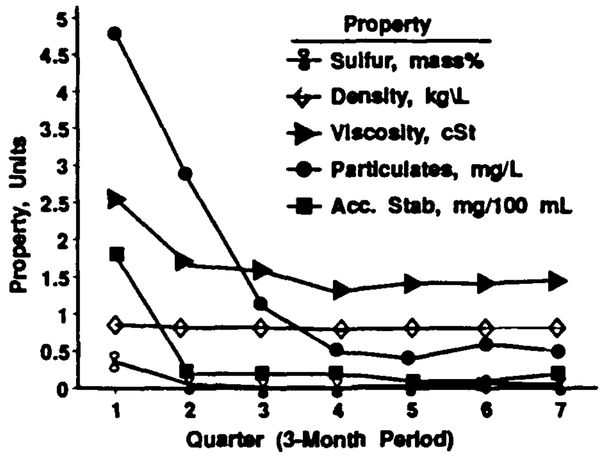
cal properties of the JP-8 fuel in the Ft. Bliss main tank located at Biggs Army Air Field (BAAF). As shown by the data, the fuel in the BAAF main tank met JP-8 specification requirements, with only a few exceptions. Several of the fuel system icing inhibitor (FSII) results are below the specification limit. These results are most likely due to partitioning of the FSII into water bottoms either during delivery or in the storage tank and are not of concern. The low values for fuel conductivity are probably due to differences in testing conditions between point of acceptance of the fuel and the BFLRF laboratory. Conductivity is very sensitive to temperature and water content. The off-specification results for particulates and visual appearance for the fifth quarter sample are due to the fact that this was an all-level sample. The bottom of the tank almost always has a water bottom and a higher particulate contamination because of settling in the tank. These contaminates are expected to settle to the bottom of the tank, and the fuel draw-off line is raised from the bottom of the tank to keep from drawing this contamination. Since the bottom of the tank was also sampled, the sample contained excess contamination, which would not be dispensed from the tank. As such, these off-specification results are not considered indicative of the condition of the bulk of the fuel in the tank.

Periodically throughout the program, samples were taken from various motor pool underground storage tanks. These samples were analyzed as a means to determine the extent of infiltration of JP-8 into the Ft. Bliss diesel fuel storage and dispensing system. Since not all tanks were sampled each quarter, (i.e., 3-month period), only average data are shown in Fig. 6(a), which summarizes results for sulfur, density, viscosity, particulates, and accelerated stability. The results in Fig. 6(a) are for middle samples only, no bottom sample results are presented. Notice that according to the data presented in Fig. 6(a), the fuel in the underground tanks seemed to reach an equilibrium somewhere between the third and fourth quarters. This is the point at which the post was declared to be totally on JP-8. Based on these fuel analyses, time periods were established to identify the transition dates from the use of diesel fuel to the JP-8-DF-2 mixture to only JP-8 fuel. The time period/transition dates for fuel usage are shown in Fig. 6(b) and TABLE 9.

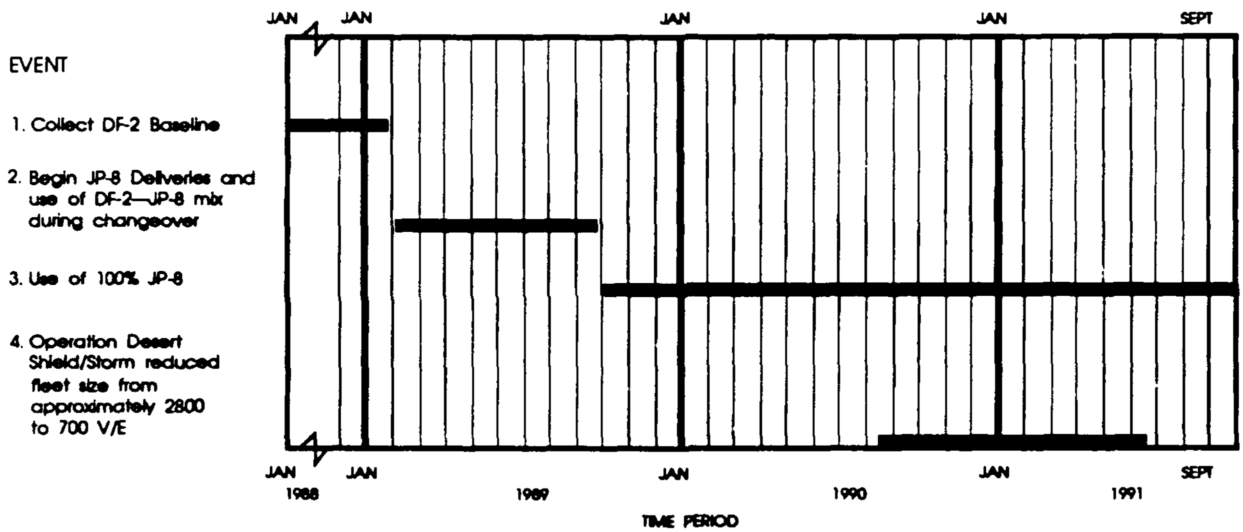
TABLE 9. Transition Dates for Fuel Usage at Ft. Bliss, TX

Date	Fuel Type
Transportation Motor Pool	
September 1988 to 28 February 1989	DF-2
1 March 1989 to 31 July 1989	Mixture
1 August 1989 to End of Program	JP-8
All Other Organizations	
1 January 1988 to 31 January 1989	DF-2
1 February 1989 to 30 September 1989	Mixture
1 October 1989 to 30 September 1991	JP-8

A fuel sample was received from Ft. Irwin, CA during the period in which the 3rd ACR was training at the National Training Center and the results are given in TABLE 10. This fuel was purchased against MIL-T-83133C, and, as such, this was the specification used for determining specification conformance. The sample met all JP-8 specifications for which it was tested. Additionally, reports from the Army General Materiel Petroleum Activity (GMPA) Lab West in Tracey, CA, indicated satisfactory tests and analyses results from samples taken from delivery trucks. Notice that the sample also met all DF-2 specifications for which it was tested, with



6(a). Underground storage tank fuel properties



6(b). Time period/transition dates for fuel usage

Fig. 6 - Fuel Property Transition Dates for JP-8 Demonstration

the exception of cetane number and cetane index. Throughout the demonstration program, the GMPA Laboratory (West) at Tracey, CA, provided BFLRF with copies of all analysis reports for samples of JP-8 fuel from Ft. Bliss, TX. TABLE 11 is a summary compilation of the reported results for 66 fuel samples analyzed by GMPA Lab West. It is apparent from the gravity, particulates, cloud point, and viscosity data in TABLE 11 that some diesel fuel or commingled samples were included in the sample analyses.

D. Operational Data Comparisons

The methods by which individual vehicle fuel dispensings were integrated with mileage (km) data to produce operational data are discussed in the following JP-8 versus DF-2 operational comparisons.

TABLE 10. Properties of Ft. Irwin JP-8

Property	Method	MIL-T-83133C	VV-F-800D	Ft. Irwin
		JP-8 Requirements	DF-2 OCONUS Requirements	AL-18737-F
Saybolt Color	D 156	Report	NR (1)	+25
Color	D 1500	NR	NR	0.5
Sulfur, Total, mass%	XRF (2)	0.3, max	0.30, max	<0.01
Distillation, °C	D 86			
Initial Boiling Point		Report	NR	186
10% Recovered		205, max	NR	203
20% Recovered		Report	NR	207
50% Recovered		Report	Report	218
90% Recovered		Report	357, max	247
End Point		300, max	370, max	278
Residue, vol%		1.5, max	3, max	0.5
Loss, vol%		1.5, max	NR	0
Flash Point, °C	D 56	NR	56, min	57
Flash Point, °C	D 93	38, min	NR	ND (3)
Gravity, °API	D 1298	37 to 51	NR	37.9
Density, 15°C, kg/L	D 1298	0.755 to 0.840	0.815 to 0.860	0.834
Kinematic Viscosity, cSt	D 445			
at -20°C		8.0, max	NR	6.63
at 40°C		NR	1.9 to 4.1	1.68
at 70°C		NR	NR	1.12
Net Heat of Combustion	D 240			
Btu/lb		18,400 min	NR	18,445
MJ/kg		42.8, min	NR	42.902
Hydrogen, mass%	D 3178	13.4, min	NR	13.7
Particulate Contamination, mg/L	D 2276	1.0, max	10, max	0.6
Fuel System Icing Inhibitor	FED-STD-791, Method 5340	0.10 to 0.15	NR	0.102
Fuel Electrical Conductivity, pS/m	D 2624	150 to 600	NR	300
Cetane Number	D 613	NR	45, min	37.8
Cetane Index	D 976-80	NR	43, min	38.2
Corrosion Inhibitor, mg/L	(4)	Report	NR	NR

(1) NR = No Requirement.
(2) X-Ray Fluorescence.
(3) ND = Not Determined.
(4) Extraction/Liquid chromatography method using HITEC E580 as standard.

TABLE 11. JP-8 Sample Analyses [U.S. Army General Materiel and Petroleum Activity (GMPA) Lab West Data]

Property	Results for 66 Samples			MIL-T-83133C JP-8 Requirements
	Minimum	Average	Maximum	
Gravity, °API	32.9	43.3	47.0	37 to 51
Visual Appearance	C&B	C&B	C&B	NR
Distillation, °C				
IBP	138	179	205	Report
10%	158	193	227	205, Max
20%	187	200	238	Report
50%	200	213	267	Report
90%	213	237	312	Report
End Pt	203	265	338	300, Max
Recovered	97.5	98.1	99.0	NR
Loss, vol%	0.1	0.8	1.8	1.5, Max
Residue, vol%	0.5	1.1	1.8	1.5, Max
Cetane Index, D 976	36.0	45.7	51.5	NR
Existent Gum, mg/100 mL	0.0	2.7	34.6	7.0, Max
Copper Corrosion, 2 hr @ 100°C	1B	—	1A	1, Max
Flash Point, °C, D 93	42	58	82	38 Min
Cloud Point, °C	-54	-46	-13	NR
Water Reaction	1B	—	1A	1B, Max
Icing Inhibitor, vol%	0.00	0.11	0.19	.10 to .15
Particulates, D 2276, mg/L	0.0	0.7	8.5	1.0, Max
K. Vis, 40°C, cSt	1.2	1.5	2.6	NR
K. Vis, 70°C, cSt	0.9	1.0	1.6	NR
NR = No Requirement				

1. Individual Vehicle Fuel Consumption

Individual vehicle miles-per-gallon (km/L) values were computed based on the merging of the TAMMS mileage data base. If chronologically correct sequences of mileage (km) and fuel dispensings resulted, then a miles-per-gallon (km/L) value was computed for each of the three fuel periods, where applicable. Thus, each individual vehicle contributed at least one mpg (km/L) figure for each fuel period in which data were collected. Vehicles were then grouped into common group types, resulting in 38 different vehicle- and equipment-engine groups. All analyses were conducted separately for the 6th ADA Bde, 11th ADA Bde, and 3rd ACR. As an example of this massive data base, TABLE 12 shows seven representative vehicle groups.

TABLE 12. Selected Vehicle Groupings

Group No.	Nomenclature	Vehicle Description
4	Howitzer, S.P.	M109A2, M109A3
8	Tank, Combat	M1A1
9	Cavalry Fighting Vehicle	M3
10	Truck, Cargo, 2-1/2 Ton	M35A1, M35A2, M35A2C, M36A2
21	Carrier, C.P.	M577A1, M577A2
26	Recovery Vehicle	M88A1
30	Truck, Cargo, 5 Ton	M923, M923A1, M927, M927A1, M928, M928A1

In order to assess whether there were significant differences in the **average** miles-per-gallon (km/L) value reported during the DF-2 period and the JP-8 period, a statistical methodology using hypothesis testing with the t-test statistic was performed. The average miles-per-gallon (km/L) values by vehicle group and fuel period were computed for the 6th ADA Bde, 11th ADA Bde, and 3rd ACR and are summarized for selected groups in TABLE 13. In the situations where there were at least 17 observations, there was no statistically significant difference in the average mpg (km/L) values between the DF-2 and JP-8 fuel periods in any of the three units tested. All statistical tests were made at the 5-percent level of significance. Complete data sets are provided in Reference 22.

TABLE 13. Average Miles/gal (km/L) by Selected Vehicle Group and Fuel Type [Mileage (km) - Fuel Dispensings Data Base]

Vehicle Group - Group No.	Fuel Type	No. of Vehicles	Averages Miles-Per-Gallon (km/L)
6th ADA Bde			
Truck, Cargo, 2-1/2 Ton - 10	DF-2	18	6.1 (2.6)
Truck, Cargo, 2-1/2 Ton - 10	Mixture	29	5.8 (2.5)
Truck, Cargo, 2-1/2 Ton - 10	JP-8	24	7.1 (3.0)
Truck, Cargo, 5 Ton - 30	DF-2	12	9.0 (3.8)
Truck, Cargo, 5 Ton - 30	Mixture	15	4.2 (1.8)
Truck, Cargo, 5 Ton - 30	JP-8	10	4.4 (1.9)
11th ADA Bde			
Truck, Cargo, 2-1/2 Ton - 10	DF-2	115	9.0 (3.8)
Truck, Cargo, 2-1/2 Ton - 10	Mixture	89	7.1 (3.0)
Truck, Cargo, 2-1/2 Ton - 10	JP-8	93	7.6 (10.0)
Truck, Cargo, 5 Ton - 30	DF-2	19	3.0 (1.3)
Truck, Cargo, 5 Ton - 30	Mixture	15	4.8 (2.0)
Truck, Cargo, 5 Ton - 30	JP-8	19	2.6 (1.1)
3rd ACR			
Tank, Combat - 8	DF-2	102	0.4 (0.2)
Tank, Combat - 8	Mixture	86	0.7 (0.3)
Tank, Combat - 8	JP-8	96	0.5 (0.2)
Cavalry Fighting Vehicle - 9	Mixture	71	2.4 (1.0)
Cavalry Fighting Vehicle - 9	JP-8	66	1.4 (0.6)
Truck, Cargo, 2-1/2 Ton - 10	DF-2	33	9.7 (4.1)
Truck, Cargo, 2-1/2 Ton - 10	Mixture	29	13.2 (5.6)
Truck, Cargo, 2-1/2 Ton - 10	JP-8	28	8.8 (3.7)
Carrier, C.P. - 21	DF-2	27	2.9 (1.2)
Carrier, C.P. - 21	Mixture	16	6.7 (2.9)
Carrier, C.P. - 21	JP-8	19	1.8 (0.8)
Recovery Vehicle - 26	DF-2	12	0.7 (1.3)
Recovery Vehicle - 26	Mixture	10	1.5 (0.6)
Recovery Vehicle - 26	JP-8	10	0.4 (0.4)
Howitzer, S.P. - 4	DF-2	9	1.2 (0.5)
Howitzer, S.P. - 4	Mixture	7	2.4 (1.0)
Howitzer, S.P. - 4	JP-8	7	1.8 (0.8)

NOTE: No statistically significant difference in the average mpg (km/L) values between the DF-2 and JP-8 fuel periods (5-percent level of significance).

2. 6th ADA Brigade Monthly Operational Reports

a. Mileage—Similar comparison tests were made with the data base developed from the 6th ADA monthly operational reports. Again, average miles-per-gallon (km/L) values by vehicle group and fuel period were computed and are shown in TABLES 14 and 15 for selected groups in the 1/43rd and 2/6th ADA Battalions, respectively. No monthly fuel usage reports were gathered for the DF-2 fuel period. However, statistical comparisons were made on the average mpg (km/L) values between the mixture and JP-8 fuel periods. In cases where there were at least 17 observations, there were no statistically significant differences (at the 5-percent level of significance) in the average mpg (km/L) values by vehicle type and fuel period in the two battalions tested.

TABLE 14. Average Fuel Consumption Values by Selected Vehicle Group and Fuel Type (6th ADA Bde, 1/43rd ADA Battalion Monthly Fuel Usage Data Base)

Mixture: February, April through September 1989			
End Item Description	Number of Vehicles	Average mpg (km/L)	Total Miles (km)
Truck, Tac, CUCV	84	12.0 (5.1)	71,129 (114,447)
Truck, Amb, CUCV	4	25.0 (10.6)	5,532 (8901)
Truck, 2-1/2 Ton	42	6.3 (2.7)	13,994 (22,516)
Truck, 5 Ton	55	4.7 (2.0)	11,800 (18,986)
Truck, HEMTT, 10 Ton	45	2.2 (0.9)	11,240 (18,085)
End Item Description	Number of Generators	Average gal/hr (L/hr)	Total Hours
Generator Set, 5 kW	6	0.62 (2.35)	644
Generator Set, 10 kW	4	0.94 (3.56)	30
Generator Set, 15 kW	31	1.09 (4.13)	3,390
Generator Set, 30 kW	12	0.41 (1.55)	2,123
Generator Set, 60 kW	1	0.61 (2.31)	87
Generator Set, 150 kW	10	7.49 (28.35)	4,071
JP-8: October 1989 through August 1991			
End Item Description	Number of Vehicles	Average mpg (km/L)	Total Miles (km)
Truck, Tac, CUCV	91	9.8 (4.2)	349,571 (562,460)
Truck, Amb, CUCV	4	11.4 (4.9)	15,203 (24,462)
Truck, 2-1/2 Ton	49	5.7 (2.4)	57,693 (92,828)
Truck, 5 Ton	79	4.1 (1.7)	67,713 (108,950)
Truck, HEMTT, 10 Ton	72	2.6 (1.1)	93,720 (150,795)
End Item Description	Number of Generators	Average gal/hr (L/hr)	Total Hours
Generator Set, 5 kW	11	0.61 (2.31)	3,316
Generator Set, 10 kW	4	2.00 (7.57)	4
Generator Set, 15 kW	53	1.21 (4.6)	22,247
Generator Set, 30 kW	13	0.70 (2.65)	4,437
Generator Set, 60 kW	1	1.07 (4.05)	465
Generator Set, 150 kW	16	9.47 (35.84)	11,273
Welder, TM	1	2.00 (7.57)	5
NOTE: No statistically significant difference in the average mpg (km/L) or gal./hr (L/hr) values between the mixture and JP-8 fuel periods (5-percent level of significance.)			

TABLE 15. Average Fuel Consumption Values by Vehicle Group and Fuel Type (6th ADA Bde, 2/6th ADA Battalion Monthly Fuel Usage Data Base)

Mixture: May through July, September 1989			
End Item Description	Number of Vehicles	Average mpg (km/L)	Total Miles (km)
Truck, Tac, CUCV	21	14.0 (6.0)	11,946 (19,221)
Truck, 2-1/2 Ton	10	4.2 (1.8)	2,989 (4,809)
Truck, 5 Ton	8	3.1 (1.2)	1,289 (2,704)
Truck, HEMTT, 10 Ton	4	0.8 (0.3)	422 (679)
Tracked Carrier	8	1.9 (0.8)	1,137 (1,829)
JP-8: October 1989 through July 1991			
End Item Description	Number of Vehicles	Average mpg (km/L)	Total Miles (km)
Truck, Tac, CUCV	25	11.7 (5.0)	35,029 (56,362)
Truck, 2-1/2 Ton	8	8.0 (3.4)	6,731 (10,830)
Truck, 5 Ton	3	3.4 (1.5)	3,547 (5,707)
Truck, HEMTT, 10 Ton	5	2.5 (1.1)	3,714 (5,976)
Tracked Carrier	11	2.2 (0.9)	4,318 (6,948)
Truck, 1-1/4 Ton	1	9.9 (4.2)	237 (381)
NOTE: No statistically significant difference in the average mpg (km/L) values between the mixture and JP-8 fuel periods (5-percent level of significance).			

b. Generator Hours—Hours of operation for diesel/turbine engine-driven generator sets were computed for the generator sets of the 1/43rd ADA Bn, 6th ADA Bde for the period 1 February, 1 April through June 1990. The figures were compiled from the monthly usage reports submitted by the battalion and are shown in Reference 22. The average hours operated per generator were calculated, and then the results multiplied by 360, the number of generator sets reportedly at Ft. Bliss during the period. The result was 66,348 hours of operation. An additional 14,550 hours were accumulated through 30 September 1991.

3. Ft. Bliss Transportation Motor Pool (TMP)

TABLE 16 summarizes the number of vehicles, total miles (km) driven, and average miles-per-gallon (km/L) computed for selected vehicles from the TMP operational data base collected at Ft. Bliss. This data base was composed of 51 vehicles, which supplied operational data from 1 September 1988 through 15 August 1991. During the JP-8 fuel period, 4 of the International Harvester 28-passenger buses, 26 of the International Harvester 44-passenger buses, and all 5 of the Crown Coach 53-passenger buses were replaced with Cummins-B 44-passenger buses. Thus, the JP-8 miles-per-gallon computations included only the data from the original vehicles. An average miles-per-gallon figure was computed separately for the Cummins-B 44-passenger buses used in the JP-8 period. The International Harvester 28-passenger bus and International Harvester 44-passenger bus vehicle types contained the largest number of vehicles. Although

TABLE 16. Ft. Bliss Transportation Motor Pool (TMP) Fuel Consumption Data (Selected Vehicles Only)

Vehicle Type	Fuel Type	No. of Vehicles	Average mpg (km/L)	Total Miles (km)
International Harvester 28-Passenger Bus	DF-2[1]	10	6.7 (2.9	55,821 (89,816)
International Harvester 28-Passenger Bus	Mixture[2]	10	6.9 (2.9)	52,160 (83,925)
International Harvester 28-Passenger Bus	JP-8[3]	9	5.6 (2.4)*	143,537 (230,951)
International Harvester 44-Passenger Bus	DF-2	25	5.8 (2.5)	104,226 (167,700)
International Harvester 44-Passenger Bus	Mixture	22	5.8 (2.5)	71,680 (115,333)
International Harvester 44-Passenger Bus	JP-8	27	5.4 (2.3)	224,248 (360,815)
Crown Coach 53-Passenger Bus	DF-2	4	5.1 (2.2)	37,441 (60,243)
Crown Coach 53-Passenger Bus	Mixture	4	5.1 (2.2)	30,728 (49,441)
Crown Coach 53-Passenger Bus	JP-8	4	4.9 (2.1)	37,500 (60,338)
International Harvester Truck, Tractor, 10 Ton	DF-2	3	6.5 (2.8)	8,731 (14,048)
International Harvester Truck, Tractor, 10 Ton	Mixture	3	6.3 (2.7)	5,613 (9,031)
International Harvester Truck, Tractor, 10 Ton	JP-8	3	5.2 (2.2)	29,891 (48,095)
Cummins-B, 44-Passenger Bus (New)	JP-8	27	5.4 (2.3)	363,308 (584,563)

[1] 1 September 1988 through 28 February 1989.
[2] 1 March 1989 through 31 July 1989.
[3] 1 August 1989 through 15 August 1991.
* Statistically significant difference in the average mpg (km/L) values between DF-2 and JP-8 fuel periods (5-percent level of significance).

the International Harvester 28-passenger bus group was comprised of only 10 vehicles (smaller than the targeted 17 used in the hypothesis testing), a statistical t-test comparing the average miles-per-gallon in the DF-2 period and the average miles-per-gallon in the JP-8 period resulted in a statistically significant difference in the average mpg values (p-value = 0.003). The average mpg for the DF-2 fuel period was 6.7, while the average mpg for the JP-8 fuel period was 5.6. Further, there were no significant differences in the average mpg (km/L) values between the DF-2 and JP-8 fuel periods for the International Harvester 44-passenger bus. The combined JP-8 fuel mileage for all TMP vehicles through 15 August 1991 was 811,818 miles (1,306,215 km). For those vehicles at Ft. Bliss that used JP-8 fuel, all users remarked about the absence of the huge clouds of black smoke that contributed greatly to the air pollution in the El Paso and Ft. Bliss areas.

4. Mileage Accrued by Unit

The total miles (km), computed from TAMMS data, for tracked and wheeled vehicles enrolled in the AOAP at Ft. Bliss are shown in TABLE 17. The figures represent estimated total mileage (km) accumulated through 30 June 1990 for combined periods using the DF-2 - JP-8 mixed fuel and the JP-8 fuel.

5. Mileage Accumulation for GM 6.2 L Powered Vehicles

TABLE 18 presents mileage accumulation for GM 6.2 L powered vehicles (CUCV and HMMWV) in the Ft. Bliss 6th ADA Bde. Of significance is the fact that CUCVs and HMMWVs are not enrolled in the Army Oil Analysis Program but still have operated with JP-8 fuel since the beginning of the JP-8 Demonstration Program. Also of importance is the fact that the

TABLE 17. Mileage (km) Accrued at Ft. Bliss by Military Unit (estimated through 30 June 1990)

Fuel	Total Miles (km)	Tracked Miles (km)	Wheeled Miles (km)
3rd Armored Cavalry Regiment			
DF-2	192,232 (309,301)/13 months	105,103 (169,111)	87,129 (140,194)
JP-8/DF-2 Mix	222,413 (357,863)/8 months	156,136 (251,223)	66,277 (106,640)
JP-8	145,749 (234,510)/9 months	95,333 (153,391)	50,416 (81,119)
6th Air Defense Artillery Brigade			
DF-2	27,252 (43,848)/13 months	384 (618)	26,868 (43,231)
JP-8/DF-2 Mix	26,930 (43,330)/8 months	194 (312)	26,736 (43,018)
JP-8	30,533 (49,128)/9 months	302 (486)	30,231 (48,642)
11th Air Defense Artillery Brigade			
DF-2	121,318 (195,200)/13 months	9,751 (15,689)	111,567 (179,511)
JP-8/DF-2 Mix	130,084 (209,305)/8 months	9,106 (14,652)	120.978 (194,654)
JP-8	110,812 (178,297)/9 months	7,433 (11,960)	103,379 (166,337)
Total Miles (km) (JP-8/DF-2 mix plus JP-8 combined use periods for above three units)	666,521 (1,072,432)	268,504 (432,023)	398,017 (640,409)
Transportation Motor Pool (All Vehicles)			
Fuel		Miles (km)	
DF2		218,743 (351,957)/6 months	
JP-8/DF-2 Mix		167,161 (268,962)/5 months	
JP8		811,818 (1,306,215)/24.5 months	

TABLE 18. Mileage (km) Accumulation in GM 6.2L Powered Engines (6th ADA Bde Monthly Fuel Usage Data Base)

	Total Miles (km)
1/43rd ADA Bn, 6th ADA Bde	
February, April 1989 through August 1991	
Truck, Tactical, CUCV	420,700 (676,906)
Ambulance, Tactical, CUCV	20,735 (33,363)
2/6th ADA Bn, 6th ADA Bde	
May 1989 through July 1991	
Truck, Tactical, CUCV	46,975 (75,583)
Summary of Accumulated Mileage, 6th ADA Bde	
Total Miles (km) Truck, Tactical, CUCV	467,675 (752,489)
Average Number of Vehicles	87
Average Number of Miles (km) per Vehicle	5,376 (8,650)
Total Miles (km), Ambulance, Tactical, CUCV	20,735 (33,363)
Average Number of Vehicles	4
Average Number of Miles (km) per Vehicle	5,183 (8,341)

CUCV/HMMWV family uses a rotary fuel injection system that is more fuel sensitive than other systems (i.e., in-line pumps, unit injectors, oil lubricated rotary pumps, etc.), and this family has the highest vehicle density in the military inventory. No comparisons with DF-2 can be made because of lack of baseline data. From actual figures supplied by the 6th ADA Bde shown in TABLE 18, it is possible to determine that, for the CUCV vehicles of that organization, an average 5,367 miles (8,650 km) were driven per truck, tactical, CUCV and 5,183 miles (8,341 km) were driven per ambulance, tactical, CUCV. Firm figures are not available for HMMWVs, and deployment to ODS greatly reduced the total number at Ft. Bliss. As of 31 July 1990, it was conservatively estimated that approximately 1,455,951 miles had been accumulated by the GM 6.2 L vehicles. By 31 August 1991, the 6th ADA Bde had accumulated another 228,136 miles of operation with CUCV vehicles.

6. Bulk Fuel Consumption

Because of the fact that JP-8 fuel has a lower volumetric net heat of combustion than diesel fuel, it was anticipated that more JP-8 fuel might be required in order to make up for the lower energy content. Based on computation alone, a determination could be made as to how much additional JP-8 fuel would be required to achieve the same energy content as a given amount of diesel fuel. In actual operation, this potential difference in amounts of fuel also depends on variation in fuel consumption of different types of V/E, variation in V/E density, and the frequency and extent of major training exercises. It was possible to account for Ft. Bliss fuel consumption by two methods, (1) acquiring total fuel consumption from bulk fuel dispensings at BAAF tank farm, and (2) acquiring fuel dispensings to individual vehicles. Bulk fuel consumption for Ft Bliss and the 3rd ACR exercises at the National Training Center, Ft. Irwin, CA, are shown in TABLES 19 and 20.

It is believed that the total bulk fuel dispensings are higher with JP-8 than DF-2 for the following reasons:

- M151A1 utility trucks (gasoline) replaced by CUCV and HMMWVs (diesel) in FY89 and FY90
- M113A1 (6V-53) personnel carriers replaced by M3 (VTA-903T) fighting vehicles in FY89
- Introduction of the HEMTT series trucks resulted in the turn-in of several M35A2/M54A2 LD(S) 465-1 trucks in FY89 and FY90
- Intentional drawdown of DF-2 during 1 QTR FY89 and 2 QTR FY89 (Jan) for initial fill of JP-8.

Since the JP-8 demonstration was to have no impact on user mission/training requirements (i.e., was to be conducted on a noninterference basis), it was not intended that the V/E fleet would be kept constant as done in a controlled fleet test. Therefore, the difference in average bulk fuel dispensings per quarter for JP-8 versus DF-2 is considered reasonable in view of the major changes in vehicle mix.

TABLE 19. Bulk Fuel Consumption at Ft. Bliss, TX

Period	Bulk Dispensings, gal. (L)		Cost	
	DF-2	JP-8	DF-2	JP-8
1 QTR FY88	461,468 (1,746,656)		$346,101	
2 QTR FY88	588,644 (2,228,018)		441,483	
3 QTR FY88	599,932 (2,270,743)		449,949	
4 QTR FY88	339,337 (1,284,391)		254,503	
1 QTR FY89	370,934 (1,403,985)		241,107	
2 QTR FY89 (Jan)	257,186 (973,449)		167,171	
2 QTR FY89 (Feb, Mar)		582,630 (2,205,255)		$355,404
3 QTR FY89		478,832 (1,812,379)		292,088
4 QTR FY89		752,426 (2,847,932)		458,980
1 QTR FY90		313,761 (1,187,585)		172,569
2 QTR FY90		813,233 (3,078,087)		447,278
3 QTR FY90		860,930 (3,258,620)		473,512
4 QTR FY90		586,111 (2,218,430)		322,361
1 QTR FY91		149,043 (564,128)		156,495
2 QTR FY91		185,651 (702,689)		194,934
3 QTR FY91		274,659 (1,039,584)		288,392
4 QTR FY91		1,086,899 (4,113,913)		1,141,244
Total	2,617,501 (9,907,241)	6,084,175 (23,028,602)	$1,900,314	$4,303,257
Average/Quarter	491,088 (1,858,769)	570,748 (2,160,282)	$356,532	$403,304

TABLE 20. Bulk Fuel Consumption for 3rd ACR at National Training Center, Ft. Irwin, CA

Period	Bulk Dispensings, gal. (L)		Cost	
	DF-2	JP-8	DF-2	JP-8
October 1987	349,926 (1,324,470)		$262,445	
May 1989	12,924 (48,917)		8,400	
May 1989		339,747 (1,285,942)		$207,246
October 1989		348,846 (1,320,382)		212,796
Total	362,850 (1,373,387)	688,593 (2,606,325)	$270,845	$420,042

7. Fuel-Wetted Components Usage

Fuel-wetted component usage was tracked for the period 1 January 1988 through 30 September 1991 from Department of Army (DA) Maintenance Request Forms 2407 provided by the Ft. Bliss maintenance division. Component usage fluctuated during calendar years 1988, 1989, 1990, and nine months of 1991 as shown in TABLE 21. For some vehicle groups, component usage increased, and in others, usage decreased with JP-8 fuel. Further contributing to this fluctuation were equipment gains and losses during 1988, 1989, and 1990. Definitely calendar year 1990 was especially significant because of ODS. The 3rd ACR, 11th ADA Bde, and the 70th Ordnance Bn as well as other smaller units were mobilized for combat. This mobilization required repair or replacement of all components considered marginal and which could adversely affect combat readiness. The effects in costs are clearly shown in TABLE 22. As average costs for parts declined overall, the costs for labor increased significantly in 1990,

TABLE 21. Fuel-Wetted Components Replacement (Reported on DA Form 2407)

Vehicle/ Equipment	Nomenclature	Calendar Year (12 month)			9 Months
		1988	1989	1990	1991
M109A2	Injector Assembly	0	0	0	5
M1008/M1009	Injector Pump	19	44	67	34
	Injector Assembly	0	0	0	16
M998	Injection Pump	0	0	4	8
M35A2	Metering Pump (2 Series)	74	82	61	12
	Injector Nozzle Assembly	250	145	68	12
M52A2	Metering Pump	40	27	23	12
	Injector Nozzle Assembly	469	77	63	18
M818/936	Fuel Metering Pump	9	3	8	3
	Injector Assembly	71	0	65	0
M939	Metering Pump	0	0	4	8
M923	Injector Pump	6	0	7	1
M915	Metering Pump (2 Series)	0	2	0	0
	Injector Assembly (2 Series)	51	0	12	0
M978/M911	Injector Pump	23	25	12	5
	Injector Assembly	0	0	64	0
M113	Injector Assembly	454	434	375	95
Generator Set, 15 kW	Metering Pump	5	5	7	1
Generator Set, 30 kW	Metering Pump	0	0	8	0
	Injector Assembly	24	0	0	6
Generator Set, 60 kW	Metering Pump	39	15	39	4
	Injector Nozzle Assembly	6	0	0	0

presumably because of hours worked overtime as vehicles and equipment were made combat ready. Even without the 1990 aberration, the steady rise in labor costs are apparent in TABLE 22. Initial complaints by user and maintenance personnel that a very large increase in the number of fuel filters was required because of JP-8 resulted in data being acquired comparing fuel filter usage in calendar years 1988 and 1989. The comparison for the 2 years is shown in TABLE 23. Subsequent investigations revealed that, in all cases, after the fuel systems were purged of solid contaminants resulting from deteriorated DF-2 and faulty maintenance practices, regularly scheduled fuel filter changes were completely adequate. An analysis of the data shown in TABLE 22 comparing fuel-wetted component repair and replacement costs in 1988 versus 1989 reveals that significant reductions in costs for labor and components exist. A discussion of cost savings and cost avoidance is included in Appendix B.

8. AOAP-Directed Oil Changes

The data collected through the Army Oil Analyses Program included standard laboratory recommendation codes, which identified when vehicles were required to change the oil based on the oil sample analysis. These lab-recommended oil changes were totaled by type of vehicle for each of the three fuel periods. A nonparametric statistical test (known as the Wilcoxon Rank Sum Test) was used to compare the number of lab-recommended oil changes per vehicle between the DF-2 and JP-8 fuel periods. Violation of the assumption of normally distributed data in each fuel group precluded the use of the t-test statistic. Although there were no statis-

TABLE 22. Fuel-Wetted Component Repair and Relacement Costs

No. of Months	Year	Total Labor Costs, Pumps	No. of Pumps	Average Labor Cost per Pump	Total Labor Costs, Injectors	No. of Injectors	Average Labor Cost per Injector
Average Labor Costs							
12	1988	$16,128.09	181	$ 89.11	$14,263.73	1271	$11.22
12	1989	15,124.34	113	133.84	5,341.54	338	15.80
12	1990	31,739.65	229	138.60	10,786.38	647	16.67
9	1991	12,123.86	82	147.85	2,981.97	168	17.75
Average Parts Costs							
No. of Months	Year	Total Parts Costs, Pumps	No. of Pumps	Average Parts Cost per Pump	Total Parts Costs, Injectors	No. of Injectors	Average Parts Cost per Injector
12	1988	$17,489.16	93	$188.06	$10.266.32	788	$13.03
12	1989	8,359.09	71	117.73	4,618.22	217	21.28
12	1990	18,268.88	111	164.58	6,018.90	437	13.77
9	1991	5,859.85	64	91.56	820.31	81	10.13
Total Hours Worked and Average Cost per Hour							
No. of Months	Year	Total Hours Labor for Pump Repair	Total Labor Cost for Pumps	Average Labor Cost per Hour	Total Hours Labor for Injector Repair	Total Labor Cost for Injectors	Average Labor Cost per Hour
12	1988	1,415.0	$16,128.09	$11.40	1,262.5	$14,263.73	$11.30
12	1989	1,039.5	15,124.34	14.55	372.0	5,341.54	14.36
12	1990	1,827.0	31.739.65	17.37	650.0	10,786.38	16.59
9	1991	683.5	12,123.86	17.74	169.5	2,981.97	17.59

TABLE 23. Comparison of Fuel Filter Usage
(Reported by 3rd ACR S-4 Class IX Section)

Engine Series	Nomenclature	Calendar Year	
		1988	1989
LD 465-1	Primary/Secondary Fuel Filter	124	50
	Fuel Filter Assembly	2	9
NHC 250	Filter Elements	0	4
DDC Series 53 and 71	Primary/Secondary Fuel Filters	173	59
AGT 1500	Fuel Filter Element (WS)	50	23
AVDS 1790-	Fuel/Water Separator Filter Parts Kit	12	9
	Primary Fuel Filter	0	3
Caterpillar, Hercules, Allis Chalmers	Primary/Secondary Filter Element	101	51
	Cartridge, Filter Strainer	1	4
GM 6.2L	Filter Assembly, CUCV	22	12

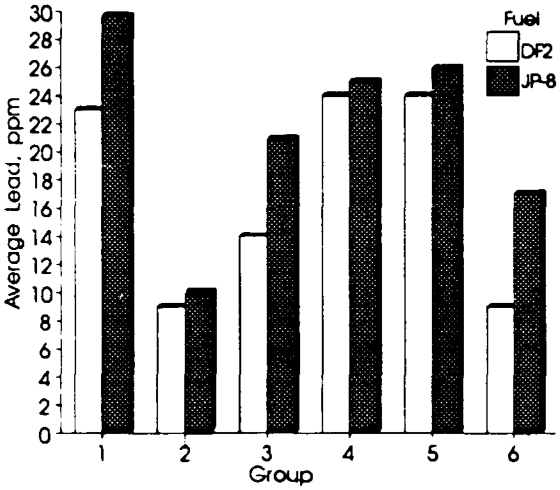
tically significant differences in the number of recommended oil changes by vehicle type between the DF-2 and JP-8 fuel periods, it is believed that the cleaner burning JP-8 fuel will result in lower wear metal contamination due to the reduction in fuel sulfur content alone, i.e. 0.36 wt% for DF-2 versus 0.03 wt% for JP-8. All tests were made at the 5 percent level of significance for gorups with at least 17 observations. TABLE 24 gives the number of vehicles and recommended oil changes per vehicle group for the period 1 January 1987 through 27 September 1991. These data were obtained from magnetic computer tapes provided by MRSA.

TABLE 24. Number of Vehicles and Oil Changes per Vehicle Group per Fuel Period from AOAP Tape: January 1, 1987–September 27, 1991

Group	Fuel Type	No. of V/E	No. of Oil Change Rec	Avg. No. of Oil Change Rec
AVLB Combat Eng. Veh. & M60A1 Tanks	DF-2	62	87	1.40
	Mixture	22	27	1.23
	JP-8	14	23	1.64
M1 & M1A1 Tanks, AGT-1500	DF-2	7	8	1.14
	Mixture	2	3	1.50
	JP-8	4	4	1.00
Mortar Carrier, Carrier Cargo; M113APC; Gun	DF-2	171	260	1.52
	Mixture	87	131	1.51
	JP-8	123	213	1.73
Howitzer, SP; Light Recovery Vehicle, DD 8V-71	DF-2	33	48	1.45
	Mixture	18	29	1.61
	JP-8	34	68	2.00
2-1/2 Ton Truck, 5-Ton Truck, LD 465-1	DF-2	52	87	1.67
	Mixture	53	66	1.25
	JP-8	71	104	1.46
M3 Bradley Fighting Vehicle, Cummins 903T	DF-2	4	4	1.00
	Mixture	30	43	1.43
	JP-8	48	72	1.50
5-Ton Truck, LDS 465-1	DF-2	31	57	1.84
	Mixture	36	55	1.53
	JP-8	49	77	1.57
5-Ton Truck, NHC 250	DF-2	78	105	1.35
	Mixture	67	88	1.31
	JP-8	68	83	1.22
Truck Tractor, HET 22-1/2 Ton, NHC 400	DF-2	34	55	1.62
	Mixture	29	35	1.21
	JP-8	33	43	1.30
HEMTT 10-Ton Truck, DD 8V-92TA	DF-2	88	109	1.24
	Mixture	53	54	1.02
	JP-8	82	109	1.33
Generator Set 15/60 Hz; Generator Set 15/400 Hz	DF-2	29	37	1.28
	Mixture	33	43	1.30
	JP-8	41	164	1.56
Generator Set 30/60 Hz	DF-2	190	22	1.16
	Mixture	11	14	1.27
	JP-8	25	31	1.24

9. AOAP Oil Degradation Data

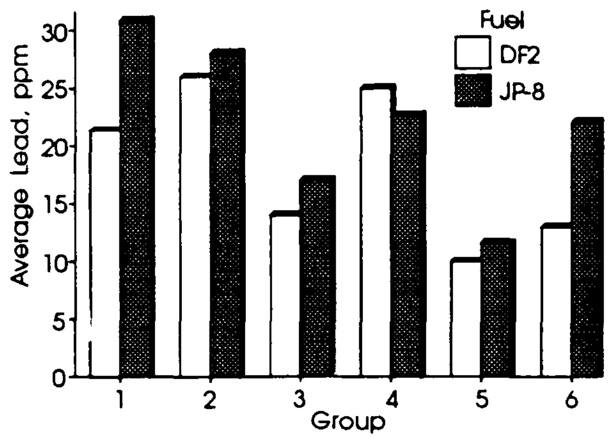
Comparisons were made between average iron (Fe), copper (Cu), and lead (Pb) readings in ppm as computed from the AOAP computer tapes for the period 1 January 1987 through 27 September 1991. The comparisons were made for 63 V/E groups operating with DF-2 and neat JP-8. Figs. 7 through 12 are bargraph displays of average wear metals (Fe, Cu, Pb) by vehicle group type and fuel period. The 15 V/E groups with statistically different average wear metal values are shown with an asterisk in the legends of these figures. Four V/E groups in



Group Description 1 = AVLB Combat & M60A1 Tanks
2 = M1 & M1A1 Tank
3 = M106A2*
4 = Howitzer & Recovery Vehicle
5 = 2-1/2-Ton & 5-Ton Trucks
6 = M3 BFV, Cummins 903T*

*Statistically significant difference in the average metal reading between the DF-2 and JP-8 fuel periods at the 5-percent level of significance.

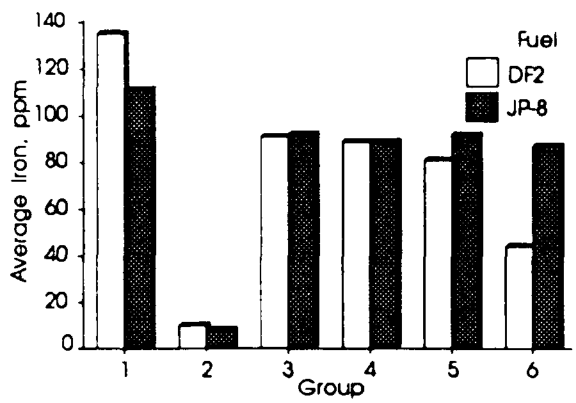
Fig. 7 - Average lead (Pb) by vehicle group by fuel period



Group Description: 1 = 5-Ton Truck
2 = Truck, HET 22-1/2 Ton
3 = 10-Ton Truck*
4 = Gen Set 30/60 Hz
5 = Gen Set 60/60 Hz
6 = Gen Set 60/400 Hz*

*Statistically significant difference in the average metal reading between the DF-2 and JP-8 fuel periods at the 5-percent level of significance.

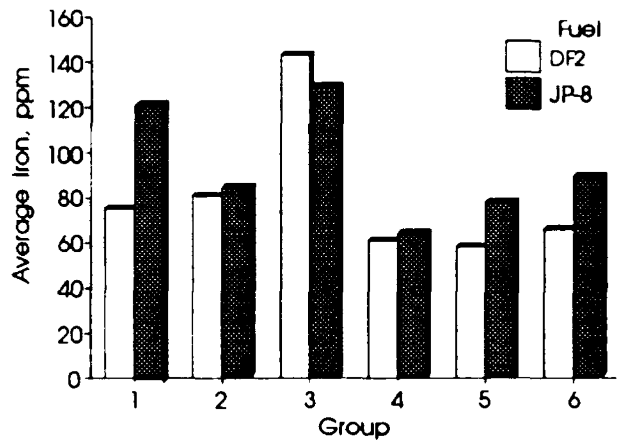
Fig. 8 - Average lead (Pb) by vehicle group by fuel period



Group Description 1 = AVLB Combat & M60A1 Tanks
2 = M1 & M1A1 Tank
3 = M106A2
4 = Howitzer & Recovery Vehicle
5 = 2-1/2-Ton & 5-Ton Trucks*
6 = M3 BFV, Cummins 903T*

*Statistically significant difference in the average metal reading between the DF-2 and JP-8 fuel periods at the 5-percent level of significance.

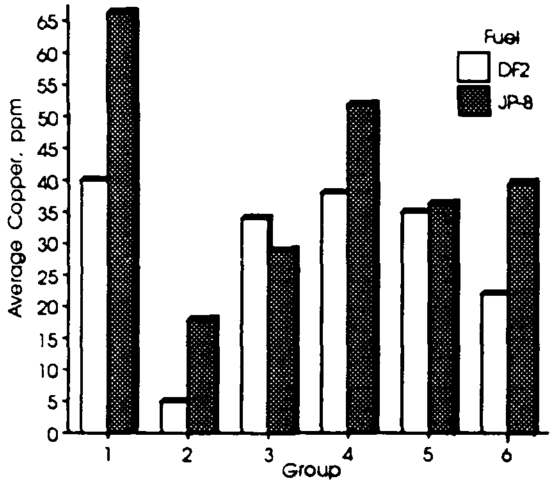
Fig. 9 - Average iron (Fe) by vehicle group by fuel period



Group Description: 1 = 5-Ton Truck*
2 = Truck, HET 22-1/2 Ton
3 = 10-Ton Truck*
4 = Gen Set 15/60 Hz*
5 = Gen Set 60/60 Hz
6 = Gen Set 60/400 Hz*

*Statistically significant difference in the average metal reading between the DF-2 and JP-8 fuel periods at the 5-percent level of significance.

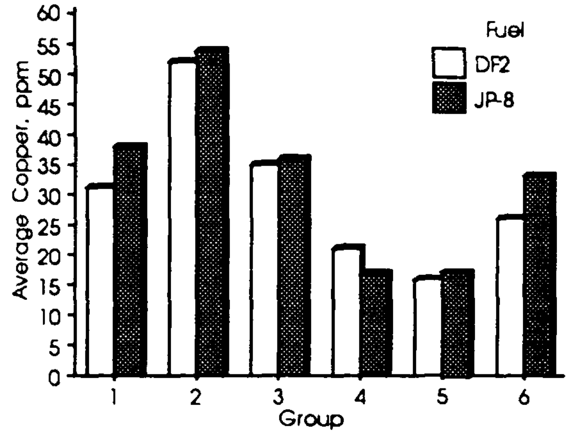
Fig. 10 - Average iron (Fe) by vehicle group by fuel period



Group Description: 1 = AVLB Combat & M60A1 Tanks
2 = M1 & M1AI Tank
3 = M106A2*
4 = Howitzer & Recovery Vehicle*
5 = 2-1/2-Ton & 5-Ton Trucks
6 = M3 BFV, Cummins 903T*

*Statistically significant difference in the average metal reading between the DF-2 and JP-8 fuel periods at the 5-percent level of significance.

Fig. 11 - Average copper (Cu) by vehicle group by fuel period



Group Description: 1 = 5-Ton Truck*
2 = Truck, HET 22-1/2 Ton
3 = 10-Ton Truck
4 = Gen Set 30/60 Hz
5 = Gen Set 60/60 Hz
6 = Gen Set 60/400 Hz*

*Statistically significant difference in the average metal reading between the DF-2 and JP-8 fuel periods at the 5-percent level of significance.

Fig. 12 - Average copper (Cu) by vehicle group by fuel period

Figs. 7 and 8 showed statistically different average lead values between the DF-2 and JP-8 fuel periods. These vehicles included: (1) M106A2 (DD 6V-53); (2) M3 Bradley Fighting Vehicle (Cummins 903T); and (3) MEP115A (AC3500), and (4) 10-Ton Truck (DD 8V-92TA). Six vehicle groups in Figs. 9 and 10 showed statistically different average iron values, while five groups in Figs. 11 and 12 demonstrated statistical differences in the average copper readings. Wear metal readings for 58 of the 63 V/E groups, including 10 of those in the statistically different category, were in the normal range for such wear metals as defined in Army TM 38-301-4. Of the remaining statistically different wear metal readings, three fell within the marginal zones, one was in the high range zone, and one reading was considered to be abnormal. There were no exceptional or alarming differences in wear metal averages between DF-2 fuel operations and JP-8 operations. It should be noted that nonspecification oil was identified at Ft. Bliss during FY89, which was suspected of having a significant impact on wear rates for the combat/tactical engines in use at the time. While the effects of using the nonspecification lubricants cannot be quantified, the shift to lubricants that do meet specification, together with the cleaner burning JP-8 fuel will result in much better engine operations with a significant reduction in internal engine wear.

VII. RESOLUTION OF USER CONCERNS

It was the practice, throughout the demonstration program, to investigate all fuel-related concerns of maintenance/use personnel. Many of the concerns were similar in nature. A summary of the concerns that surfaced during the course of the program is presented in TABLE 25,

coded according to the following subsections in which they are discussed. More detail on these user concerns is provided in Reference 22.

TABLE 25. Summary of Ft. Bliss User Concerns Using JP-8 Fuel

Item	Subject Concern
A	Safety (vapor/fumes, skin contact)
B	Filter Plugging
C	Fuel Metering Equipment
	1. Electromechanical Fuel System
	2. Three DD6V-53 Barrel and Plunger Assemblies
	3. Complete DD6V-53 Unit Injector
	4. NHC-250 Barrel Plunger Assemblies
D	Power Output
	1. Transportation Motor Pool 44-Passenger Buses
	2. M915 Line Haul Tractor
	3. D7E Full-Tracked Bulldozer
	4. Front-End Bucket Loaders
	5. M88A1 Recovery Vehicle
	6. Ft. Bliss DIS Dynamometer Testing
E	Fuel Consumption - CUCV
F	Vehicle Personnel Heater
G	Vehicle Cooling
H	M911 Fuel Cell Fill Cap Plugs Melting
I	M1A1 Plugged In-Line Check Valves
J	Vehicle Engine Exhaust Smoke System (VEESS)

A. Safety

Two safety concerns were raised by user personnel. People assigned to clean the inside of bulk fuel storage tanks or fuel tankers raised questions about volatility/vapors and toxicity of JP-8 compared with diesel fuel (DF-2). The toxicity issue was investigated earlier by the U.S. Army Environmental Hygiene Agency (USAEHA) and the Office of the Surgeon General (OTSG). These two agencies prepared a Health Hazard Assessment Report (HHAR) for the use of JP-8 fuel in tactical vehicles. (26) This report addressed potential health hazards identified as handling, combustion emissions, and interaction with Halon 1301 during fire suppression. The conclusions stated in this report were that the health hazards identified for JP-8 appear to be equal to or less than those associated with diesel fuel (DF-2). An additional safety matter surfaced that concerned flammability of JP-8 if splashed on hot engine exhaust pipes. This issue was of no consequence and is further discussed in subsection VII.H, "M911 Fuel Cell Fill Cap Plugs Melting."

B. Filter Plugging

Numerous instances of filter plugging were reported in the first several months of the program. Fuel and fuel filter samples were obtained and analyzed at BFLRF. The analyses showed that the filters were plugged by a combination of diesel fuel deterioration products, dirt, dust, and sand. Microbiological contamination was not found to be a largely contributing factor. However, the presence of microbiological growth in the fuel cells could not be entirely ruled out due to the presence of water in several of the fuel cells. The diesel fuel deterioration products were from diesel fuel remaining in vehicle/equipment fuel cells at the beginning of the demonstration program. JP-8 did not in any way cause, or contribute to, the filter plugging. The filter plugging problems disappeared as dirty fuel cells and lines were cleaned, scheduled fuel

filter changes made, and the remaining diesel fuel consumed. JP-8 fuel was not responsible for the contamination that resulted in filter plugging.

C. Fuel Metering Equipment

1. Electromechanical Fuel System

There were initial concerns that fuel was not being properly metered to the engine combustor by the electromechanical fuel systems (EMFS) for the M1A1 Abrams tanks. Discussions with maintenance personnel of the 3rd ACR failed to establish if the failures of the M1A1 vehicle EMFS units were mechanical or electrical. The simplified test equipment (STE) for the M1 vehicle merely diagnosed a faulty unit; it did not isolate an electrical or mechanical fault. The failed units were evacuated to Anniston Army Depot (ANAD) for repair/overhaul. ANAD personnel stated that 60 to 80 percent of the EMFS units turned in for repair were for electrical problems; of the units with mechanical problems, the majority were due to "contaminated fuel." It was speculated, but not confirmed that "contaminated" or deteriorated DF-2 caused material incompatibility that lead to spool valve sticking within the EMFS units. No instances of EMFS failure could be directly attributed to the use of JP-8 fuel.

2. Three DD6V-53 Barrel and Plunger Assemblies

Three DD 6V-53 barrel and plunger assemblies were received at BFLRF for analysis that were removed from depot-issued engines by Ft. Bliss shop personnel. Typically, depot engines either can be issued to direct support user activity as a replacement for a removed engine, or, in this instance, the engine was issued to the DIS shops for preparation of a power pack. After dynamometer power checks, the engine is shut down to prepare for running a stall check on the transmission. Upon restart of the engine, the fuel injectors were determined to be faulty, possibly seized, and removed from the engine. The three barrel and plunger assemblies were removed from the same engine. Since the three barrels/plungers were received without respective unit injector bodies, there is a distinct possibility that the wear surfaces had been distressed by their removal before their examination at BFLRF. With this possibility in mind, three possible seizure mechanisms were proposed upon examining the surfaces. The first is the "infant mortality" mechanism in which tolerances, surface finish, concentricity, and manufacturing debris can contribute to seizure. This mechanism was demonstrated as relatively uniformly scored surfaces on two of the assemblies. Another mechanism occurs when small particles are introduced into the injector during assembly or pass through the injector screen filters and become wedged between the barrel and plunger, thus scratching the surfaces. These scratches can increase the amount of asperity contact, which can eventually cause a scored surface, resulting in a seizure. These same two assemblies revealed thin vertical scratches, which would indicate that small particles had been wedged between barrel and plunger. The third mechanism occurs when a particle distresses the sharp shoulder of the plunger helix as it crosses the fill/spill port. The third assembly revealed this mechanism, in which significant areas of the plunger

helix had been fractured. The debris from the fractured helix then causes seizure when it is wedged between the barrel and plunger surfaces. The failure modes cited are not deemed to be fuel-related regardless of which fuel is used.

3. Complete DD 6V-53 Unit Injector

BFLRF also received a complete DD 6V-53 unit injector that had failed under similar circumstances as the above barrel/plunger assemblies. The injector fuel inlet and outlet filter screens were rinsed and all particulate trapped. An elemental X-ray analysis of the fuel inlet filter particulate revealed Al, Si, Fe, Ca, Cu, and Zn. It appears Al, Si, and Fe were the most abundant of the elements found. The fuel outlet filter particulate analysis revealed, F, Al, Si, Ca, Cu, and Fe, of which the most abundant elements were Al, Si, and Fe. The abundance of Fe was greater on the outlet filter, indicating that scoring had occurred in the barrel/plunger assembly. After a careful disassembly, the barrel/plunger were inspected and revealed a fractured shoulder on the plunger helix. In addition, a small particle was found lodged in a distressed area of the plunger. An elemental analysis of the particle revealed Al, Si, Na, and Cl.

BFLRF believes these failures are not a JP-8 related issue, but rather a manufacture/rebuild cleanliness/handling issue. These failures were similar to those observed in earlier work. (27)

4. NHC-250 Barrel/Plunger Assemblies

Three governor barrel and plunger assemblies of PT fuel metering pumps from NHC-250 Cummins engines received from the Ft. Bliss DIS Component Repair Facility were inspected. The service histories of the fuel metering pumps were unknown. Two of the barrel/plunger assemblies were disassembled and revealed no signs of scoring or scuffing, both precursors to seizure. It was noted that the plungers could be inserted into their respective barrels and rotated and translated freely. The third assembly had the plunger seized in the barrel.

The two assemblies that were free arrived in that condition, but had been reported at Ft. Bliss as being seized. Although the plungers did not show any evidence of seizure, an examination of the governor barrel, with a reference to the Cummins PT Fuel Pump Rebuild and Calibration Manual, revealed a possible failure mechanism. The manual states that failure of the plunger can occur due to overheating during extended periods of overspeeding. This occurs when the governor flyweights force the plunger stop collar against the governor barrel face. Although the components are fuel wetted, neither the small bearing area of the plunger stop collar nor the barrel face are designed as thrust washers; therefore, a hydrodynamic fuel film cannot be developed to support the thrust load. This would result in metal-to-metal contact and overheating. The plungers received had their stop collars removed, but the barrel faces were highly polished, indicating extended plunger stop collar/barrel face contact did occur. A PT fuel pump that has seen laboratory dynamometer service was disassembled to examine the governor plunger and barrel. The assembly revealed a dull surface on the barrel face, indicating plunger

stop collar/barrel face contact had not occurred in the pump. It is believed the failure of the two Ft. Bliss assemblies can be attributed to overheating due to governor plunger stop collar/barrel face contact and is **not** a JP-8 related problem.

A possible failure mechanism for the third assembly can also be found in the PT fuel pump manual. The manual states that seizure of the governor plunger in the barrel can occur during engine overspeeding due to improper engine speed control caused by improper use of gearing and braking. The manual does indicate this failure mode is more likely to occur in VTA-903 engines due to their higher engine speeds, but it does not rule out the possibility of occurrence in N/NH/NT series engines. An examination of the governor barrel face indicated that governor plunger stop collar/barrel face contact had not occurred in this assembly. It is believed the plunger/barrel seizure can be attributed to overspeeding.

The Cummins PT Fuel Pump Rebuild and Calibration Manual indicates that governor plunger/barrel assembly failures occur due to overspeed conditions, and is not a fuel-related problem. All facts considered, the conclusion is that governor plunger/barrel assembly failures are **not** a JP-8 related condition.

D. Power Output

1. Transportation Motor Pool 44-Passenger Buses

A performance test was conducted on a fully loaded Transportation Motor Pool (TMP) 44-passenger bus powered by a recently remanufactured IHC-DT466B engine. The vehicle's fuel tank was drained and refilled with JP-8 fuel and new fuel filters installed. The vehicle was loaded to capacity and driven 10 miles (16.1 km) on a designated route. Observations were made on acceleration, speeds attained, and overall performance. The following day the vehicle's fuel tank was drained and refilled with DF-2 fuel (fuel filters were not replaced). The vehicle was once again loaded to capacity and driven the same route as the previous day. There were no noticeable differences in performance between the two fuels.

2. M915 Line-Haul Tractor

A BFLRF monitor accompanied a convoy from Ft. Bliss, TX, to Ft. Irwin, CA, as an observer on an M915 line-haul tractor from the 62nd Transportation Company, 70th Ordnance Battalion. The purpose of the trip was to obtain firsthand observations of operator claims of loss of power when operating the M915 on JP-8 fuel. A simplified test equipment/internal combustion engines (STE/ICE-R) unit was taken along to monitor fuel pressure at the fuel filter and to monitor engine power of the Cummins NTC-400 engine. The test vehicle fuel tanks were drained and then topped off with JP-8, and the fuel filters were changed. The test vehicle carried a cargo of an estimated 26,000 pounds (11818 kg), which was considered to be the heaviest load in the convoy. During the course of the convoy, two refueling stops were made at which all vehicles topped off with commercial DF-2. This refueling allowed the BFLRF monitor to ob-

tain firsthand observations of the M915 operating on JP-8 and DF-2. The BFLRF monitor and vehicle operator did not observe any performance degradation while the M915 was operating on JP-8. The test vehicle was able to maintain speed on grade and its convoy position in all but two occasions during the trip. The exceptions in which the vehicle could not maintain speed on grade occurred one time with JP-8 and once with DF-2. The inability to maintain position is attributed to the heavier load carried by the test vehicle, as evidenced by the same vehicle response with both fuels. The BFLRF monitor indicated there was no discernible difference in performance of the M915 between the two fuels. The vehicle operator concurred with the monitor's observations.

3. D7E Full-Tracked Bulldozer

A comparative JP-8 versus DF-2 fuel test was conducted in December 1989 on a single D7E full-tracked tractor (bulldozer) in response to complaints by operators of power loss and engine overheating while using JP-8 fuel. The tractor is powered by a Caterpillar D 339T/A engine and operated by the 3rd ACR. The test objectives were to dig two identical combat tank hide positions side-by-side by the same tractor using JP-8 and DF-2 fuels and record start-to-finish times. Approximate dimensions for the hide positions were 175 ft long by 13 ft wide (53.3 m x 4.0 m). A 5-foot (1.5 m) firing platform was placed facing the opposition side followed by a 45-degree cut to a depth of 14 feet (4.3 m) ending with an exit ramp of 30-degree slope. In preparation for the test, the tractor was thoroughly checked, the fuel filter replaced, and then trucked to a test site. The first position was dug using JP-8 fuel, and the start-to-finish time was 50 minutes. The fuel tank was completely drained of JP-8 fuel and filled with 40 gallons (151 L) of DF-2 fuel. The tractor was operated at high idle for 20 minutes to ensure that all the JP-8 fuel was purged from the system. The second hide position was then dug using DF-2 fuel, and the start-to-finish time was 40 minutes.

Since the 20 percent time difference favoring DF-2 was more than could be expected due to fuel heating value and viscosity differences, it was decided that another comparative test would be conducted. Two D7E full-tracked tractors (bulldozers) powered with Cat D 339T/A engines were operated by 3rd ACR combat engineers in follow-up comparative fuel evaluations during June 1990. Working side-by-side, each dozer sequentially excavated two main battle tank hide emplacements, each operated initially with JP-8 followed by DF-2. There were two engineer operators, one for each tractor, with no operator switching between tractors. After completing the first dig, an HEMTT tanker defueled the JP-8 from each tractor and refueled each tractor with DF-2. Results of the excavations are shown in TABLE 26.

It was noted that the left steering lever of tractor E-54 had a faulty hydraulic control valve that failed to return to the centered position. As a result, the vehicle pushed to the right, scraping the side during the dig. The operator was forced to apply the brake to the left track for steering compensation. Since the operator had not previously operated vehicle E-54, it was felt that the JP-8 dig took a longer time due to lack of operator proficiency in counteracting the

TABLE 26. JP-8 vs DF-2 Comparative Excavation Results

	Tractor E-53		Tractor E-54	
	JP-8	DF-2	JP-8	DF-2
Elapsed Time, min	90	108	111	74
Total Dig Time, min	74	71	86	60
Ambient Temp, °F (°C)	89-90 (32)	96-98 (36-37)	89-90 (32)	96-98 (36-37)
Max Coolant Temp, °F (°C)	230-250 (110-121)	230-250 (110-121)	230-250 (110-121)	230-250 (110-121)

sideward pushing tendency of the vehicle. Hence, the dig time with DF-2 was noticeably shorter as the operator became more adept at correcting the vehicle's sideward pushing tendency. Tractor E-53 shows a 4-percent difference in dig time in favor of DF-2; this is more in line with the expected difference due to use of JP-8 fuel than was observed in the previous comparison with JP-8 conducted in December 1989. The difference in excavation times was commensurate with a calculated difference based on the net heat of combustion for DF-2 and JP-8 fuels. The Engineer Training School (ATSE-CDM-S) was contacted to determine the operator/vehicle performance targets used to conduct various engineer tasks. The Engineer Training School representatives indicated that the school was not aware of any time limits for site preparations. Operators are taught to do the best they can considering soil composition, moisture, elevation, and temperature conditions at time of operations.

4. Front-End Bucket Loaders

An issue of power loss and overheating on the front bucket loaders reported by Engineer maintenance section personnel was investigated by the BFLRF monitor. According to the noncommissioned officer in charge of the heavy equipment section, the front bucket loaders have never experienced power loss and overheating due to JP-8 use. At the beginning of the JP-8 demonstration program, there were complaints of power loss and overheating in one of the bucket loaders. However, the problem was found to be a partially plugged fuel filter and a faulty radiator, neither of which was caused by the JP-8 fuel.

5. M88A1 Recovery Vehicle

The 3rd ACR maintenance personnel expressed concern about the lack of power in the M88A1 armored recovery vehicle during operation with JP-8. When towing an M1A1 tank on a straight level road with an M88A1 using DF-2, an average speed of 20 to 22 mph (32 to 35 km/hr) was observed; using JP-8 for the same job produced an average speed of 14 to 15 mph (22 to 24 km/hr). The problem is compounded because the M88A1 is marginally powered, with DF-2, when recovering M1 vehicles. There is no noticeable difference with JP-8 fuel when the M88A1 is pulling its own weight, or when hoisting power packs or performing other stationary functions. In recognition of the M88A1 marginal power problem, the Army Tank Automotive Command with assistance from Teledyne Continental Motors (Government Products Division) developed a fuel injection pump adjustment procedure to be used for the AVDS-1790-2DR engine that powers the M88A1 vehicle. A field evaluation of this pump adjustment procedure with JP-8 fuel was planned during the JP-8 demonstration, but was deferred until

after ODS to allow 3rd ACR participation.The evaluation was performed at Ft. Bliss in December 1991. (28)

6. Ft. Bliss DIS Dynamometer Testing

The DIS Component Repair Facility provided dynamometer test results on rebuild engines from 06 June 1989 through 31 July 1990. BFLRF staff in coordination with the Tank-Automotive Command provided the Component Repair Facility with the minimum acceptable brake horsepower/speed ratings on DF-2 and JP-8 fuel for all engines repaired at Ft. Bliss. As shown in TABLE 27, all engines with the exception of the VTA-903T surpassed the minimum bhp(kW)/rpm allowed for JP-8 fuel. The Ft. Bliss facility repaired the first VTA-903T engine in April 1990; consequently, the result depicted for this engine is based on one test only.

TABLE 27 - Ft. Bliss Rebuild Engine Dynamometer Test Results (June 1989-July 1990)

Engine Type	Minimum Allowed bhp (kW) at rpm		Dynamometer Test Results with JP-8, Avg Max bhp (kW)
	DF-2 Fuel	JP-8 Fuel	
6.2 L	124 (92.5) at 3600	112 (83.6) at 3600	122 (91.0)
6V-53	202 (151) at 2800	182 (136) at 2800	205 (153)
NHC-250	210 (157) at 2800	200 (149) at 2800	209 (156)
8V-92T	387 (289) at 2100	368 (275) at 2100	380 (284)
VTA-903T	480 (358) at 2600	456 (340) at 2600	450 (336)
LDT-465-1C	134 (100) at 2600	134 (100) at 2600	136 (102)
LDT-465-1A	170 (127) at 2600	170 (127) at 2600	172 (128)
AC3500	130 (97.0) at 2000	120 (89.5) at 2600	134 (100)

E. Fuel Consumption—CUCV

A complaint was received through the Army Tank Automotive Command Logistics Assistance Representative that a CUCV in the 1/43rd ADA Battalion had a range of 300 miles (483 km) when using DF-2 and only 150 to 175 miles (242 to 282 km) when operating on JP-8. To investigate this complaint, the BFLRF monitor requested the concerned unit obtain the actual CUCV for a comparative fuel consumption test. The fuel tank of the CUCV was drained, the fuel filter cleaned, and 15 gallons (57 L) of JP-8 were added. The driver, his NCO, and the BFLRF monitor drove the vehicle over a 69.2-mile (111 km) route, drained the fuel, and measured the unconsumed JP-8 fuel. Fifteen gallons (57 L) of DF-2 were added, without a fuel filter change, and the CUCV was operated over the same 69.2-mile (111 km) route with the same operator and the same number of personnel. At the completion of the run, the DF-2 was drained, and the unconsumed fuel was measured. Fuel consumed and mpg (km/L) for JP-8 versus DF-2 were 4.34 gal.(16.4 L)/15.9 mpg (6.76 km/L) and 4.25 gal./16.3 mpg (16.1 L and

6.93 km/L), respectively. This comparison convinced unit operators that the difference in vehicle range with JP-8 when compared with DF-2 was insignificant.

F. Vehicle Personnel Heater

A comparative test was scheduled and conducted on a vehicle-mounted personnel heater in which performance with JP-8 fuel was compared against DF-2. With the cooperation of the Ft. Bliss DIS, the test was conducted at the special components repair shop with two TACOM LARs and the BFLRF monitor present as observers. Results showed the difference in air temperature for the two fuels was less than 10°F (4°C). Startability was the same for the two fuels, with both reaching the same levels of heat within a few seconds of each other. In two instances, the JP-8 fueled heater reached 8° to 9°F (3°C) higher air temperature than the DF-2 fueled heater at the same setting. In one instance, DF-2 produced 5°F (2°C) higher air temperature than the JP-8. The conclusions reached were that there are no significant differences in heater operation using the two fuels.

G. Vehicle Cooling

Operators of the 3rd ACR M1A1 tanks complained that the tanks were running hotter, but not overheating, with JP-8 fuel than they had with diesel fuel. Similar complaints arose at the National Training Center (NTC) at Ft. Irwin, CA. A Textron-Lycoming representative at Ft. Irwin used a testing device on an M1A1 to determine the difference between the temperature attained with JP-8 fuel and a reference temperature attained when the vehicle was operated with DF-2. The temperature attained with JP-8 fuel was 100°F (approximately 55°C) above the DF-2 temperature, but was still well within the M1A1's operating temperature parameters. Similar complaints occurred with D7E bulldozers, M109A3 self-propelled howitzers, front-end bucket loaders, and M3 Bradley fighting vehicles. As the demonstration program progressed, complaints about overheating gradually disappeared.

H. M911 Fuel Cell Fill Cap Plugs Melting

The Ft. Bliss TACOM LARs reported a problem of pressure relief plugs melting in fuel tank caps on the M911 tractors operating in the demonstration program. Initially, it was believed that the JP-8 fuel was producing higher exhaust temperatures and the proximity of the fuel tank filler cap to the exhaust pipe was causing the alloy in the plugs to melt. However, data showed that exhaust port temperatures when using JP-8 fuel are generally ±50°F when compared to diesel fuel. Of primary concern was the possibility of fire caused by fuel splashing from the vent holes and coming in contact with the hot exhaust pipe.

Investigation revealed that the tractors were equipped with an older design filler cap whose relief plugs were filled with an alloy that had a lower melting point than the new replacement cap. Additionally, upon splashing from the vent holes and exposure to the exhaust pipe, JP-8 fuel offers equal or less fire hazard than would diesel fuel.

I. M1A1 Plugged In-line Fuel Check Valves

Maintenance personnel at the 1st Squadron, 3rd ACR reported that plugged check valves in the M1A1 tank had caused problems in several of the vehicles. The check valve allows fuel to transfer from front to rear fuel cells and is automatically actuated when the fuel in the rear cells drains down to 1/4 full level. Maintenance personnel stated they had observed plugging of these valves. This phenomena continued even after the front fuel cells were drained and flushed before being refilled with JP-8 fuel. Although annoying to maintenance personnel, the plugged check valves are relatively easy to clean and reinstall. The plugging frequency eased off as remaining contaminants in the fuel cells gradually worked their way through the fuel system. Samples of the plugging debris were not available for analysis, and, hence, composition could not be determined. As previously stated, the contamination in the tank fuel cells was not caused by JP-8 fuel.

J. Vehicle Engine Exhaust Smoke System (VEESS)

The reduced capability of JP-8 to produce smoke when used in onboard vehicle engine exhaust smoke systems (VEESS) was raised as an Armor School Issue at a February 1988 review. Because of the nature of the problem, the development of a program to fix the problem was beyond the scope of this demonstration and was addressed by other agencies. Appropriate correspondence on the VEESS/JP-8 issue was brought to the attention of Ft. Bliss personnel.

VIII. MAJOR FIELD EXERCISES

In addition to the normal mission training cycles at Ft. Bliss, several major exercises were conducted wherein JP-8 was used. In these exercises, Ft. Bliss either hosted visiting units from other home bases, or Ft. Bliss units deployed to the National Training Center in Ft. Irwin, CA, for exercises. These exercises are discussed below in relation with the involved Army combat unit.

A. 194th Armored Brigade: Ft. Knox, KY

This unit completed its "Desert Legion" exercise at Ft. Bliss on 04 March 1989. In response to concerns that fuel consumption would increase significantly when using JP-8 fuel, calculations were made by the 194th Armored Brigade's S-4 section and BFLRF staff. Combined results showed a 2.4-percent increase with JP-8 fuel. This increase was considered insignificant. The 194th Armored Brigade was reportedly pleased with the way that the use of JP-8 fuel ended fuel waxing problems that had been experienced in prior year exercises when DF-2 fuel had been used.

B. 3rd ACR: Ft. Bliss, TX

This unit conducted major exercises at the National Training Center, Ft. Irwin, CA, in May 1989 and October 1989. A BFLRF monitor was present at the National Training Center (NTC), Ft. Irwin, CA, during these training exercises. Daily visits were made to the training area, and maintenance/user personnel were questioned as to the performance of their respective equipment using JP-8 fuel. During the first exercise in May 1989, there was reported filter plugging in several combat vehicles, i.e, main battle tanks, personnel carriers, and self-propelled howitzers. However, investigation showed that the problem was caused by deteriorated DF-2 in fuel cells of vehicles being used for the first time since the changeover to JP-8 fuel. There were no other fuel-related problems reported by units of the 3rd ACR for the remainder of the exercise nor during the October 1989 exercise.

C. 11th ADA Brigade: Ft. Bliss, TX

This unit conducted "Roving Sands" at Ft. Bliss in August 1989 and "Roving Sands 90" in May 1990. The 11th ADA Brigade's "Roving Sands 90" exercise was the largest air defense artillery exercise ever conducted in the United States. More than 8,000 soldiers, airmen, and marines took part in the exercise at Ft. Bliss, TX. No problems were reported due to the use of JP-8.

IX. OPERATION DESERT SHIELD/STORM

Coincidentally and without plan, deployment of major units from Ft. Bliss in summer 1990 to Operation Desert Shield (ODS) produced a unique fuels utilization experience for logistics, user, and maintenance personnel. Initially, JP-8 (or JP-5 for shipboard use) was intended for use by all aircraft and diesel fuel-consuming ground equipment. When it was determined that JP-8 fuel (including its three mandatory additives) was not widely available throughout the ODS theater, Jet A-1 was directed for use in all ground equipment. Selected units were, however, permitted use of DF-2 because of the need for battlefield smoke capability.

Of significant note is that there were only minimal fuel-related complaints for the units deployed to ODS from Ft. Bliss and other worldwide locations where ground equipment experience existed with use of either JP-8 or JP-5 fuels. Although these facts were initially obscured in the beginning of unit deployments to Southeast Asia (SA) due to the massive efforts to resolve logistic and maintenance problems and unit site location movements, it later became clear that those units that accepted Jet A-1 and stayed with it were mission capable much earlier than those units that had brought their fuel with them and elected to stay with diesel (DF-M in SA). Units having used only DF-2 in the past and electing to use the in-country DF-M fuel experienced many real/perceived fuel-related problems when switched to Jet A-1 that included: fuel filter plugging (due to deteriorated diesel fuel or occurrence of microbiological debris); concern for potential increased flammability (JP-8 has minimum flash point of

100°F (38°C) compared with 133°F (52°C) for DF-2); and potential for increased failure rate in fuel injection pumps (due to Jet A-1 having lower viscosity than DF-2 and Jet A-1 does not use the corrosion inhibitor mandated in JP-8/JP-5 fuels). Refer to TABLE 2 for further comparison of fuel property differences.

There were numerous fuel injection pump failures of the rotary type used in Army/DOD diesel engine generator sets and in the family of HMMWV/CUCVs. Many of the failures were pump seizure and drive shaft shear believed due to lack of corrosion inhibitor/anti-wear agent in Jet A-1 versus JP-8, and/or the much lower viscosity of Jet A-1 versus DF-2. Further investigation suggested the failures in general were brought on by increased V/E usage (almost 24 hours/day); consistently high ambient temperatures; severe duty cycles; sand/dust/water contamination; unauthorized addition of oils/fluids to the Jet A-1 fuel, believed to reduce wear; governor weight retainer flex-ring failures; and ultimate life cycle effects. In a research program already underway at BFLRF, extensive wear studies showed that appropriate additives effectively reduce the steady running wear normally seen with diesel fuel and/or the lighter aviation kerosene fuels. However, work to date has not identified any additive to prevent fuel injection pump shaft shearing of the type observed in ODS equipment. Studies in this area are continuing.

A technical report on "Performance of Fuels, Lubricants, and Associated Products Used During Operation Desert Shield/Storm" containing the results of a Belvoir RDE Center after-action survey was distributed by Belvoir RDE Center in August 1992. (29) This report, in addition to information about experience with fuels, lubricants, and related products during ODS, contains information about injector pump failure analyses and lubricity evaluations following ODS. Technical reports discussing these analyses and evaluations include References 30 through 34.

A comprehensive update of the JP-8 Fuel Demonstration Program at Ft. Bliss, TX and a preliminary statement of the impact that Operation Desert Storm had on the program were presented at the Society of Automotive's Engineers' International Congress and Exposition held in Detroit, MI on 24-28 February 1992. (35)

X. CONCLUSIONS AND RECOMMENDATIONS

A. General Conclusions

- A JP-8 demonstration program was conducted at Ft. Bliss, TX, during the period 1 February 1989 through 30 September 1991 in three major organizations, one medium/heavy truck batallion, and one missile range activity, having a total of over 2,800 vehicles/equipment (V/E).
- Approximately 6,084,175 gallons (23,028,602 liters) of JP-8 fuel were dispensed to user units at Ft. Bliss and Ft. Irwin (NTC) during the course of the demonstration program.

- The JP-8 demonstration program verified that JP-8 fuel can be used in diesel fuel-consuming V/E.

- There were no catastrophic failures due to the use of JP-8, nor any insurmountable JP-8 related concerns either during routine or major field training exercises.

- All problems surfaced by maintenance/user personnel were resolved by technical consultation or direct comparison tests with DF-2.

- A request by Ft. Bliss to continue the use of JP-8 fuel in lieu of JP-4 aviation fuel and DF-2 diesel fuel after 30 September 1991 was approved by the Department of the Army. The request was initiated because Ft. Bliss personnel believed that reduced labor and parts costs and increased combat readiness resulting from using a cleaner storing and burning fuel were too beneficial to relinquish by returning to the use of DF-2. In addition, the sudden and continued absence of black smoke generated by all diesel-burning V/E at Ft. Bliss was particularly noted and appreciated by personnel at Ft. Bliss.

B. Specific Conclusions

- No special modifications to current fuels-handling equipment nor changes to current practices are required with the use of JP-8 in ground V/E. Normal fuel filter/separator element changes, according to routine procedures, are sufficient.

- The use of JP-8 fuel did not cause or exacerbate any V/E fuel filter plugging. All instances of filter plugging were caused by contaminated or deteriorated diesel fuel remaining in the fuel cells.

- Where power loss was apparent, generally it was commensurate with the difference in heating values between JP-8 and DF-2.

- No instrumentally measured differences in engine operating temperatures supported any claim of overheating.

- For the period 01 February 1989 through 30 June 1990, TAMMS data revealed 268,504 miles (432,022 km) were accumulated by tracked vehicles and 398,017 miles (640,409 km) by wheeled vehicles for a total of 666,521 miles (1,072,432 km) using DF-2/JP-8 mix and JP-8 fuels. Because of Operation Desert Storm, no further data could be generated through TAMMS; therefore, the mileage figures shown could not be updated.

- Monthly usage data supplied by the 6th ADA Bde yielded a total of 768,954 miles (1,237,246 km) of which 488,410 miles (785,852 km) were accumulated by CUCV vehicles and 280,544 miles (451,395 km) were accumulated by the remaining combat/tactical vehicles, all using a DF-2/JP-8 mix initially and then JP-8 fuel only.

- A special study to establish total approximate miles accumulated by CUCV vehicles was performed for the period 1 February 1989 through 30 June 1990, while all participating organizations were still at Ft. Bliss. The study established the average miles per CUCV for that period and then multiplied the value by 623, the number of CUCVs reportedly at Ft. Bliss. The resultant figure, 1,460,935 miles (2,350,644 km),

was then augmented by another 228,136 miles (367,070 km) accumulated through 30 September 1991, giving a total of approximately 1,689,071 miles (2,717,715 km) accumulated by CUCVs at Ft. Bliss for the JP-8 Demonstration Program.

- It was estimated that 66,348 hours of operation were accumulated in diesel/turbine engine-driven generator sets using DF-2/JP-8 mix and JP-8 fuels during the period 1 February 1989 through 31 July 1990. An additional 14,550 hours were accumulated by the 6th ADA Bde through 31 August 1991 for a total of 80,898 hours of operation during the JP-8 Demonstration Program.

- Combined mileage (km) accumulated using JP-8 fuel in transportation motor pool (TMP) vehicles was 811,818 miles (1,306,215 km) for the period 1 August 1989 through 15 August 1991.

- In addition to the above mileage figures, the 1/43rd ADA Bn, 6th ADA Bde accumulated a total of 103,898 (167,172 km) additional miles during the period 1 October 1989 through August 1991. The 2/6th ADA Bn, 6th ADA Bde accumulated another 24,563 miles (39,522 km) during the period 1 October 1989 through 31 July 1991.

- For the period 01 January 1988 through 30 September 1991, there were no statistically significant differences observed in average V/E group fuel consumption between JP-8 and DF-2 fuel (derived from merger of TAMMS and DA Form 3643 data). Also, there were no statistically significant differences between DF-2/JP-8 mix and JP-8 fuel derived from actual usage data provided by the 6th ADA Brigade. In the TMP, there was a statistically significant difference between the DF-2 and JP-8 values for the 28- passenger buses. These were old buses and were replaced during the program.

- For the period 01 January 1988 through 30 September 1991, fuel-wetted component replacements fluctuated. For some vehicle groups, injector/injection pump usage increased and in others usage decreased with JP-8 fuel. Further contributing to this fluctuation were equipment gains and losses during the program period. It cannot be determined from these data if the use of JP-8 fuel had a statistically significant difference in component usage. However, the 3rd ACR showed reduced numbers of fuel filters were required during use of JP-8 fuel; a larger data base is needed to verify this trend.

- There were no statistically significant differences in the number of recommemded oil changes per vehicle/equipment between the DF-2 and JP-8 fuel periods tested at the 5-percent level of significance.

- Of 63 vehicle groups/wear metal combinations, 48 had no statistically significant differences in the average wear metal reading between JP-8 and DF-2. Fifteen combinations had statistically significant differences in the average wear metal reading. Thirteen of the combinations showed lower wear metal readings with DF-2 and two showed lower wear metal readings with JP-8 compared to DF-2. Ten wear metal readings were within the normal range of wear metal parameters established in TM 38-301-4, "Joint Oil Analysis Program Manual," dated 1 September 1987 with changes. Also, five other wear metal readings showed a distribution of one high range reading (JP-8), one abnormal reading (JP-8), and three marginal readings (one JP-8 lower than DF-2 and two DF-2 lower than JP-8).

- Since there were no major differences in fuel procurement cost, V/E fuel consumption, or AOAP-directed oil changes, it is judged that no cost penalty is associated with the use of JP-8 fuel. There was a substantial cost reduction in fuel-wetted component replacements during the period 1988 through 1989.

C. Recommendations

Recommendations resulting from this study include the following:

- Pertinent fuel regulations with instructions for receiving, handling, storing, and dispersing JP-4, JP-8, JP-5 and Jet A-1 fuels should be updated to address JP-8's status as not only the primary fuel for all U.S. military forces but also as the "Single Fuel on the Battlefield."
- Information documents about using JP-8/JP-5/Jet A-1 fuels to include definitions, properties, and capabilities should be prepared and distributed down to user level as soon as possible.
- Specific recommendations for changeovers from JP-4 and diesel fuels to JP-8 (Jet A-1) or JP-5 are included in Appendix C.

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APPENDIX A

Bulk Fuel and Sample Handling Procedures

A. Bulk Fuel Handling

The process of obtaining fuel for the Army begins with the determination of estimated yearly fuel requirements for all activities at a given post/camp/station. These estimates also include fuel required for various training exercises involving visiting units and training at other locations. Based on these requirements, the Defense Fuel Supply Center (DFSC) contracts with appropriate refiners/suppliers to have the required fuel made available at the appropriate Defense Fuel Supply Point (DFSP). At this point, DFSC takes custody of the fuel and is responsible for its quality. Upon receipt of requisitions, DFSC arranges for fuel to be shipped to the user (Ft. Bliss/Ft. Irwin). Once the fuel is off-loaded into the user's tanks, the Army takes custody of the fuel. Fig. A-1 is a flow diagram of this entire process at Ft. Bliss, TX.

All JP-8 deliveries to Ft. Bliss were made to the 240,000-gallon storage tank at the Biggs Army Air Field (BAAF). The 240,000-gallon storage tank was cleaned and resealed during December 1988 by a local firm under contract. The lines were flushed and cleaned and filters replaced. The Army General Materiel and Petroleum Activity (GMPA) and BFLRF personnel

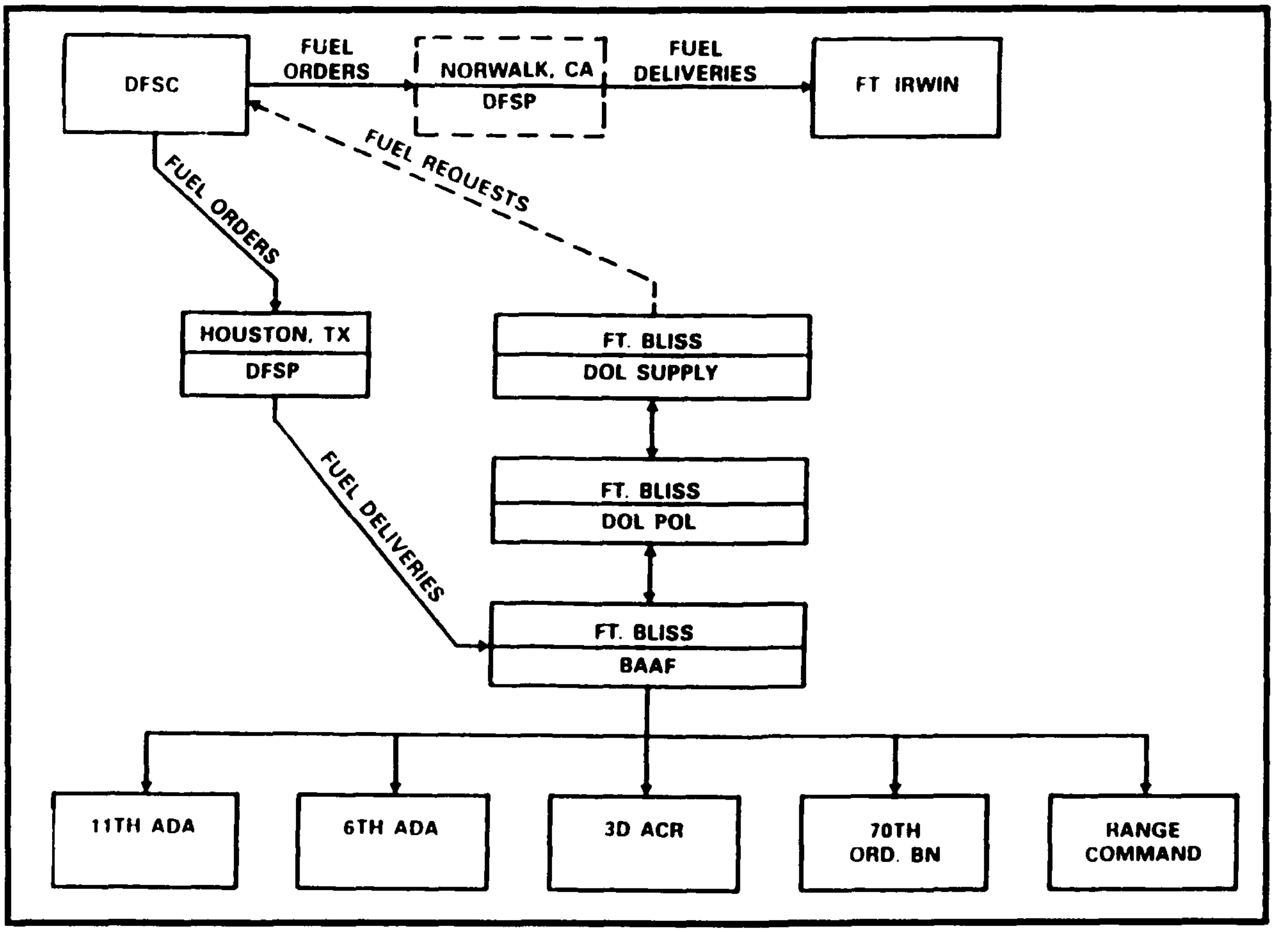

Fig. A-1 - Flow chart for requisition and delivery of JP-8 fuel during the demonstration program

inspected the tank after the work was completed and approval was granted to fill the tank with JP-8 fuel.

For the initial fill, JP-8 fuel was trucked in from 31 January through 3 February 1989. Thirty-two 7,500-gallon tanker trucks were unloaded during this period. The fuel continued to be trucked in until 16 February when the first rail tanker car arrived at BAAF. The fuel continued to be delivered by rail tanker cars with the exception of emergency shipments that occurred when fuel-dispensing volumes increased unexpectedly. The Military Traffic Management Command dedicated 20 rail tanker cars to transport the JP-8 fuel from Houston, TX, to BAAF.

From the BAAF main tank, the JP-8 is taken, using tank trucks/Heavy Expanded Mobility Tactical Trucks (HEMTT refuelers), to underground storage tanks in the individual motor pools. These tanks range in size from 5,000 to 20,000 gallons. While units of the 3rd ACR were training at Ft. Irwin, JP-8 fuel was stored in a precleaned, dedicated storage tank. Individual V/E were fueled from tankers, HEMTTs, and tank and pump units.

B. Fuel Sampling and Analysis

Two types of fuel samples were taken during the demonstration program:

- Routine samples, taken to confirm the grade and quality of fuel either being delivered to Ft. Bliss or already in storage at a given site on the post.
- Nonroutine samples, taken to aid in resolving a fuel-related problem or as additional information for a V/E performance test.

In general, the method of sampling was determined by the fuel container (i.e., storage tank, fuel cell, etc.), access to the container, and the purpose for taking the sample. All samples were taken into clean, 1-gallon epoxy-lined cans. Many of the railroad tank car samples were taken as dip samples. The remaining samples were taken using either a bomb-type thief or a small vacuum pump. Dispensing pump samples were taken only to determine the quality of the fuel being dispensed. All samples were returned to BFLRF for analysis. During the demonstration program, the fuel was to be used for ground vehicles. However, the decision was made at the beginning of the program that, in order to keep with the "One Fuel Forward" concept, and because the fuel was purchased under the JP-8 specification, the fuel must meet aviation fuel standards. This requirement meant that all fuel handling and analyses must be conducted in accordance with JP-8 requirements, as stated in MIL-T-83133C. Analyses conducted on the routine samples included most of those required under MIL-T-83133C, as well as additional analyses normally associated with diesel fuel, such as cetane number, but of special interest to this program because the fuel was to be used in ground vehicles. TABLE A-1 presents a list of the routine analyses conducted on each sample. Also presented in TABLE A-1 are the requirements for VV-F-800D diesel fuel, grades DF-1 and DF-2 for comparison. The analysis of nonroutine samples was conducted on an individual basis according to the requirements for that situation.

TABLE A-1. Routine Sample Analysis Protocol

Specification Grade		MIL-T-83133C	VV-F-800D	
Property	ASTM Method	JP-8	DF-1	DF-2 CONUS
Total Acid No., mg KOH/g	D 3242	0.015, max	NR*	NR
Aromatics, vol%	D 1319	25.0, max	NR	NR
Olefins, vol%	D 1319		5.0, max	NR
Sulfur, mass%	D 4294		0.30, max	0.5, max
Hydrogen, mass%	D 3178	13.4, min	NR	NR
Distillation, °C	D 86			
Initial Boiling Point		Report	NR	NR
10% Evaporated		205, max	NR	NR
20% Evaporated		Report	NR	NR
50% Evaporated		Report	Report	Report
90% Evaporated		Report	288, max	338, max
End Point		300, max	330, max	370, max
Residue, vol%		1.5, max	3, max	3, max
Density, kg/L	D 1298	0.840 to 0.775	Report	Report
Cloud Point, °C	D 2500	NR	Regional	Regional
Flash Point, °C	D 93	38, min	38, min	52, min
K. Vis, cSt, at				
40°C	D 445	NR	1.3 to 2.9	1.9 to 4.1
70°C	D 445	NR	NR	NR
Net Heat of Combustion	D 240			
MJ/kg		42.8, min	Report	Report
Btu/lb		18,400, min		
Btu/gal.		NR		
Cetane Number	D 613	NR	40, min	40, min
Cetane Index	D 976	NR	40, min	40, min
Existent Gum, mg/100 mL	D 381	7.0, max	NR	NR
Particulate Contamination, mg/L	D 2276	1.0, max	10, max	10, max
Accelerated Stability, mg/100 mL	D 2274	NR	1.5, max	1.5, max
FSII, vol%		0.10 to 0.15	NR	NR
Fuel Conductivity, pS/m		150 to 600	NR	NR
Corrosion Inhibitor, mg/L		QPL-25017	NR	NR
Visual Appearance	D 4176	Clean/Bright	Clean/Bright	Clean/Bright
Colonial Pipeline Co. Haze Rating	Proposed	NR	NR	NR
Color	D 156	Report	NR	NR
*NR = No Requirement.				

Fuel analysis reports were also received from the General Materiel Petroleum Activity laboratory at Tracey Army Depot. These reports were the results of analysis of samples routinely sent to GMPA for quality assurance/quality conformance testing. GMPA has final jurisdiction over the quality of POL products procured and used by the Army. The data supplied by GMPA were collected, distributed, and were very useful as additional confirmation of fuel quality.

APPENDIX B

Cost Savings and Avoidance

I. COST SAVINGS

A. Fuel

Although a comparison of the average cost per gallon of DF-2 fuel with the average cost per gallon of JP-8 fuel could yield a saving for units of Ft. Bliss and the 3rd ACR at the National Training Center (NTC), no extrapolation could be used to predict future cost savings by using JP-8 as the primary fuel for military V/E. The DOD costing system and the impact of future conversions to JP-8 fuel by the U.S. Air Force and the remaining elements of the Army make fuel cost savings a moot question at this point.

B. Fuel-Wetted Components

There was a definite savings in replacing and repairing injector/metering fuel pumps and injector nozzles for the calendar years 1988 and 1989. Maintenance DA Forms 2407 provided by the DIS, Ft. Bliss, were examined and the data reduced to the results shown in TABLE C-1. Data from the DA Forms were also received for 1990 and 1991. However, the data for these two years were skewed by preparations to make Ft. Bliss units combat ready (mission capable) for duty in the Middle East and could not be correlated with earlier data. A comparison of the number of fuel filters reported by the 3rd ACR S-4 Class IX Section for 1988 with the numbers of fuel filters used in 1989 shows a decrease of 57 percent. The true significance of this is not the cost savings in filters alone but in the greatly reduced non-mission capable time for the vehicles with plugging filters. According to the Motor Maintenance Officer, 1/70th Armored Bn, Ft. Polk, LA, a typical M1 tank with plugged filters is first affected by a reduction in power (as evidenced by a reduction in speed). Then when the filters are found plugged, the power pack has to be removed from the engine compartment, all filters removed, a biocide added, and then a 24-hour delay while the biocide kills the microbiological growth in the fuel. The fuel systems then must be flushed and replaced with a clean fuel. All told, a total of 36 hours is required to rid a tank of microbiological growth of which 12 hours are spent in several mechanics working at an average $15 per hour. During the 12 hours, a $53 primary filter and a $213 annual service kit are installed plus the new fuel. This is why so many uninformed

TABLE C-1. Cost Savings (DA Form 2407) for Fuel-Wetted Components

<table>
<tr><th>Calendar Year</th><th>Injector/Metering Pumps</th><th>% Decrease</th><th>Injector Nozzles</th><th>% Decrease</th></tr>
<tr><td colspan="5">Total Labor Costs</td></tr>
<tr><td>1988</td><td>$16,128.09</td><td rowspan="3">6</td><td>$14,263.73</td><td rowspan="3">62.5</td></tr>
<tr><td>1989</td><td>$15,124.34</td><td>$ 5,341.54</td></tr>
<tr><td>Amount of Decrease</td><td>$ 1,003.75</td><td>$ 8,922.19</td></tr>
<tr><td colspan="5">Total Component Costs</td></tr>
<tr><td>1988</td><td>$17,489.16</td><td rowspan="3">52</td><td>$10,266.32</td><td rowspan="3">55</td></tr>
<tr><td>1989</td><td>$ 8,359.09</td><td>$ 4,618.22</td></tr>
<tr><td>Amount of Decrease</td><td>$ 9,130.07</td><td>$ 5,648.10</td></tr>
</table>

commanders were upset and frustrated when confronted with the filter plugging problem during ODS.

II. COST AVOIDANCE

There is no question that military units having to draw, handle and store one fuel will be far more cost-effective that drawing, handling, and storing two or more fuels (JP-4, diesel, and kerosene). Again, there is no cost that can be placed on having military V/E mission capable at all times. JP-8 was agreed upon for use in military ground and aviation assets because it is safer and less volatile than JP-4 for aircraft and a cleaner storing and cleaner smelling fuel than diesel. It also does away with the "M1 Mix" practices to prevent waxing and freezing of diesel fuels in cold weather.

APPENDIX C

Conversion From Diesel Fuel and JP-4 to JP-8 Fuel

I. SAFETY

(1) All mandatory safety precautions must be observed when receiving, storing, or transferring any fuel.

(2) Any aviation turbine fuel whether JP-8, JP-5, or Jet A-1 must be handled as aviation turbine fuel at all times, even when used in ground combat/tactical vehicles and equipment. This practice is particularly important when intermixing JP-4 fuel currently used in most military aircraft, with any of the three kerosene fuels. Maintenance and fuel-handling personnel must be informed of the presence of JP-4 in aircraft fuels to prevent probable tragic accidents from occurring.

(3) Aviation turbine fuels must meet military specifications whether used in aircraft or ground assets. All bulk fuel handlers should be supplied with an instrument for measuring conductivity in the kerosene fuels when delivered to the bulk fuel site to ensure that the concentration of the static dissipator additive in the fuel meets the MIL-SPEC requirements. Other additive concentrations in the fuel must be detected and measured by normal laboratory tests and analyses.

(4) No special modifications in current fuel-handling equipment are required for aviation turbine fuels.

II. CONVERSION FROM DIESEL FUEL TO AVIATION TURBINE FUELS

a. Bulk Fuel Storage

(1) Draining/cleaning of all motor pool storage tanks and individual vehicle/equipment fuel cells is generally not recommended as this is beyond consideration due to costs, manpower, etc.

(2) If storage tank (i.e., bulk or intermediate) locations have been experiencing problems related to presence of micro-organisms, sterilization of these tanks is recommended by injection of approved biocides provided under MIL-S-53021 as introducing JP-8 may not kill all microbiological growth. (NOTE: Procedures for sterilization can be provided upon request to Belvoir RDE Center, Attn: SATBE-FL.)

(3) For conversion of collapsible tanks previously exposed to diesel fuel, collapsible tanks should first be checked for possible leaks after replacement with JP-8. The first few fuel batches should be tested for contamination by diesel fuel and solid contaminants. Testing should include water separation index and particulates. All fuel discharged from these collapsible tanks should be passed through a filter separator. If filter separators had previously been used for diesel fuel, new filter elements must be installed.

(4) Recipients of aviation turbine fuels at bulk storage areas should ensure that all fuels received meet the respective MIL-SPEC requirements. Experience has shown that if some suppliers think that no aviation assets will use the fuel, they will deliver fuel only qualified for ground V/E, which would defeat the "One Fuel on the Battlefield" concept.

(5) Change filter separator elements in all fuel-dispensing pump equipment previously used for diesel fuel; also change fuel-dispensing pump final filter at above or below ground storage areas that were used for diesel fuel.

b. Maintenance/User Personnel

(1) Clean all vehicle refuelers/tankers, change filter separator elements, and ensure that these separator elements are in place and in use for all dispensing operations.

(2) Draw down all M1 battle tanks' front and rear fuel cells.

(3) Change vehicle fuel filters only in accordance with established maintenance schedules; more frequent filter changes should be made only if filter plugging occurs.

(4) LARs, maintenance and user personnel should be made aware that older V/E having had a lengthy period of operation with CONUS DF-2 and recently transferred from CONUS to Outside Continental US (OCONUS) locations would prove to have more fuel system problems. The same caveat holds true for vehicles of units conducting training exercises at Ft. Bliss, TX, and Ft. Hood, TX, because both posts have converted to JP-8 use in lieu of DF-2 fuel.

(5) It is to be remembered that the application of a biocide to fuel cells does not "dissolve" any microbiological growth or other solid contaminants and that the contaminants will continue to plug fuel filters and fuel systems until the fuel cells and fuel systems are clean.

III. CONVERSION FROM JP-4 FUEL TO JET A-1/JP-8/JP-5 FUELS*

a. Safety

(1) Conversion from JP-4 to JP-8 or JP-5 fuel may increase aircraft maintenance and degrade system safety due to increased fuel leaks caused by the high swell properties of JP-4 and the "permanent set" taken by seals (especially fluorosilicone) after prolonged periods of operation with JP-4 fuel. Those aircraft deployed from CONUS are most likely to experience fuel leakage. The introduction of (conversion to) Jet A-1, JP-8, or JP-5, all of which have low swell properties, will result in seal/sealant shrinkage and the leakage of seals, which have taken a "permanent set." These problems are further aggravated by transition from high ambient ground temperatures to low flight temperatures. These fuel leaks may occur anywhere in the fuel system, engine, jet fuel starter or auxiliary power units. Fuel leakage problems can usually be resolved by the tightening of variable cavity-threaded (Wiggins-type) fuel couplings, replacement of "O" rings, or the reinjection of fuel tank sealants.

(2) The mixing of high-volatility (JP-4) and low-volatility (JP-8/JP-5/Jet A-1) fuels has always been a safety concern. This concern is due to the fact that the two types of fuels have radically different flammability ranges and, when mixed or during mixing operations, the flammability characteristics of the mixture can vary from one extreme case to the other. As an

*Letter, Department of the Air Force, ENF, to: HQ, USAF/LEYX (CSS-LRC); HQ, SAC/LGSF; SA-ALC/SFTH; HQ, MAC/LGSF; and HQ, TAC/LGSF, Subject: Desert Shield Fuel Issues, dated 25 September 1990.

example, JP-4 is normally flammable throughout the range of -20°F to + 60°F and JP-8 is normally flammable throughout the range of + 80°F to + 130°F. When two different fuels are mixed (switch loading) in aircraft tanks, the mixture is likely to be flammable at some time during the refueling operation regardless of the temperature. This flammability can be hazardous if electrostatic discharge or other ignition sources are present during the refueling. Experience with the C-130 containing reticulated blue foam has demonstrated a propensity toward an increase in fuel tank ignitions during switch loading from JP-4 to JP-8, or Jet A-1 fuels. For this reason, the USAF suggests that switch loading be minimized. Of particular concern would be the case in which (over the wing) gravity refueling is conducted, and of even greater concern is when a fuel tank contains ESM blue foam. This condition could result in a flash fire and subsequent injury to the servicing personnel and possible aircraft damage.

(3) Inter-mixing or switch loading of JP-4 and JP-8 (Jet A-1) fuel will increase the probability of vapor ignition and, therefore, should be minimized.

b. Bulk Fuel Storage

(1) Ideally, bulk storage tanks should be completely drained of JP-4 fuel and then purged with nitrogen. If nitrogen is not available, extreme care must be taken (grounding, etc.) until the aviation turbine fuel displaces all JP-4 from the storage tanks.

(2) As with fuel-handling equipment for fueling ground V/E, there are no requirements to change out or modify existing fuel-handling equipment.

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